INK JET RECORDING HEAD, ITS MANUFACTURING METHOD, INK JET RECORDER, AND METHOD FOR DRIVING INK JET RECORDING HEAD

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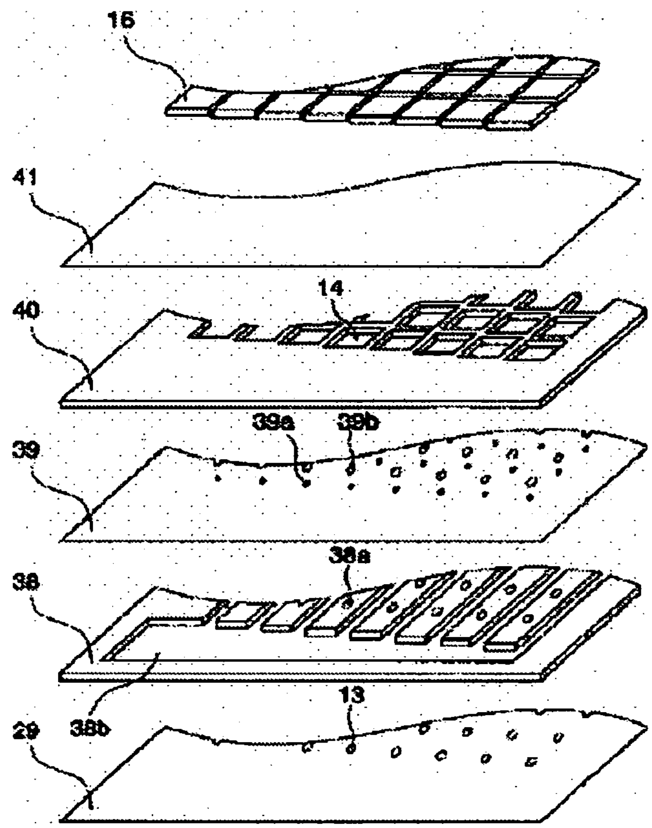
Abstract of **JP2003039673**

PROBLEM TO BE SOLVED: To provide an ink jet recording head which can discharge 'large drops' of a required size from the same nozzle while avoiding a head size increase and a cost increase, and can enhance the efficiency for discharging ink drops per unit area by realizing a 'nozzle density increase'. SOLUTION: The ink jet recording head is provided with nozzles 13, pressure chambers 14 which communicate with nozzles 13, a diaphragm 41 which forms a part of wall faces of the pressure chambers 14, and piezoelectric actuators 16 joined to the diaphragm 41 correspondingly to pressure chambers 14. A pressure wave is generated into the ink filled in the pressure chambers 14 when a vibration element comprising the diaphragm 41 and the piezoelectric actuators 16 is deformed, whereby ink drops are discharged from nozzles 13. An acoustic capacity of the vibration element is set to be not smaller than 2.0× 10<-20> [m<5> /N] in the ink jet recording head.



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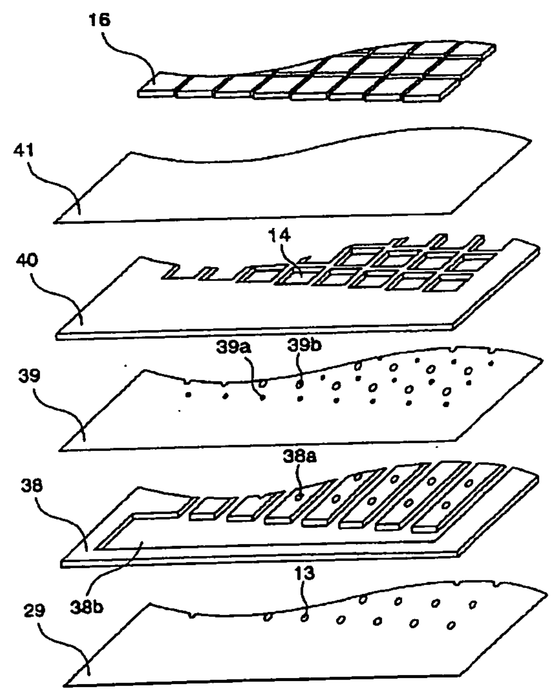
(54)【発明の名称】 インクジェット記録ヘッド及びその製造方法、インクジェット記録装置、並びにインクジェット記録ヘッドの駆動方法

(57)【要約】
【課題】 ヘッドサイズの大型化やコストアップを回避しつつ、同一ノズルから所要サイズの「大滴」を吐出させ、且つ「ノズル密度増加」を実現して単位面積当たりのインク滴吐出効率を高めることができるインクジェット記録ヘッドを提供する。
【解決手段】 本インクジェット記録ヘッドは、ノズル１３と、ノズル１３に連通する圧力室１４と、圧力室１４の壁面の一部を形成する振動板４１と、圧力室１４に対応するように振動板４１と接合された圧電アクチュエータ１６とを備え、振動板４１と圧電アクチュエータ１６とから成る振動要素が変形して圧力室１４内に充填されたインク内に圧力波を発生させることにより、ノズル１３からインク滴を吐出させる。本インクジェット記録ヘッドでは、振動要素の音響容量が2.0×10^{-20} [m^5/N]以上に設定されている。



【特許請求の範囲】

【請求項１】　ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインク内に圧力波を発生させることにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドであって、

前記振動要素の音響容量が、$2.0\times10^{-20}\mathrm{m^5/N}$以上であることを特徴とするインクジェット記録ヘッド。

【請求項２】　前記振動要素の音響容量が$5.5\times10^{-19}\mathrm{m^5/N}$以下に設定されることを特徴とする、請求項１記載のインクジェット記録ヘッド。

【請求項３】　前記振動要素に印加される駆動電圧波形の制御に応答して、前記ノズルから吐出するインク滴の滴体積が多段階に変化することを特徴とする、請求項１又は２に記載のインクジェット記録ヘッド。

【請求項４】　前記ノズルから吐出されるインク滴の最大滴体積が１５ｐｌ以上であることを特徴とする、請求項１乃至３の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項５】　前記１５ｐｌ以上のインク滴の吐出時に印加される前記駆動電圧波形が、前記圧力室の体積を収縮させる方向に電圧を印加してインク滴を吐出させる第1電圧変化プロセスと、前記圧力室の体積を膨張させる方向に電圧を印加する第２電圧変化プロセスとを含むことを特徴とする、請求項４に記載のインクジェット記録ヘッド。

【請求項６】　前記ノズルから吐出されるインク滴の最小滴体積が４ｐｌ以下であることを特徴とする、請求項１乃至５の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項７】　前記４ｐｌ以下のインク滴の吐出時に印加される前記駆動電圧波形が、前記圧力室の体積を膨張させる方向に電圧を印加する第1電圧変化プロセスと、前記圧力室の体積を圧縮する方向に電圧を印加し前記ノズル内に該ノズルの開口径よりも小さな径の液柱を形成し該液柱の先端からインク滴を分離させて微小なインク滴の吐出を行うための第２電圧変化プロセスとを含むことを特徴とする、請求項６に記載のインクジェット記録ヘッド。

【請求項８】　前記圧力室及び圧電アクチュエータの各平面形状におけるアスペクト比が夫々略１に設定されることを特徴とする、請求項１乃至７の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項９】　前記圧力室の平面寸法（平面積）が０．０９～０．５ｍｍ^{2}に設定され、前記振動板及び圧電アクチュエータの厚みが夫々、５～２０μｍ及び１５～４０μｍに設定されていることを特徴とする、請求項８に記載のインクジェット記録ヘッド。

【請求項１０】　前記振動要素の平面形状が、略正三角形、略正方形、略正六角形又は略円形であることを特徴とする、請求項１乃至９の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１１】　前記略正三角形、略正方形又は略正六角形の平面形状を有する振動要素は、相互に隣接する各２辺の接合部分が曲線状に形成されていることを特徴とする、請求項１０に記載のインクジェット記録ヘッド。

【請求項１２】　前記圧力室の幅をＷ、前記圧力室の中心と前記圧電アクチュエータの駆動部の中心との位置ずれ量をδ、前記圧電アクチュエータの幅をW_pとすると、次式

$W_p \leqq (W-2\delta)$ 又は $W_p \geqq (W+2\delta)$

を満足することを特徴とする、請求項８乃至１１の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１３】　前記圧力室の幅をＷ、前記圧力室の中心と前記圧電アクチュエータの駆動部の中心との位置ずれ量をδ、前記圧電アクチュエータの幅をW_pとすると、次式

$0.9(W-2\delta) \leqq W_p \leqq (W-2\delta)$

を満足することを特徴とする、請求項８乃至１１の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１４】　前記振動要素の音響容量が前記圧力室の音響容量より大きく設定されることを特徴とする、請求項１乃至１３の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１５】　前記圧力室内で発生する圧力波の固有周期をT_c、前記振動要素及び圧力室の合成音響容量をc_c、前記振動要素のイナータンスをm_0とすると、次式

$m_0 < 2.5\times10^{-4}\,T_c^{2}/c_c$ [kg/m^4]

を満足することを特徴とする、請求項１乃至１４の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１６】　前記ノズルから吐出したインク滴が、６００ｄｐｉ以下の記録解像度で記録媒体上に着弾することを特徴とする、請求項１乃至１５の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１７】　前記圧力室内に発生する圧力波の固有周期が１５μｓ以下に設定されることを特徴とする、請求項１乃至１６の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１８】　前記圧電アクチュエータが、前記圧力室に相当する領域に配置された駆動部と、前記圧力室の外壁に相当する領域に配置された電極パッド部と、前記駆動部及び電極パッド部の双方を連結するブリッジ部とを備えることを特徴とする、請求項１乃至１７の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項１９】　前記ブリッジ部が、前記駆動部の中心から離れた位置に連結されることを特徴とする、請求項１８に記載のインクジェット記録ヘッド。

【請求項２０】　前記ノズルがマトリクス状に２次元配列されることを特徴とする、請求項１乃至１９の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項２１】　前記圧力室及び振動要素がマトリクス状に２次元配列されることを特徴とする、請求項１乃至２０の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項２２】　前記圧電アクチュエータが複数配列された圧電アクチュエータ領域の外周部を取り囲むようにダミーパターンが配設されることを特徴とする、請求項２１に記載のインクジェット記録ヘッド。

【請求項２３】　前記ダミーパターンが、前記圧電アクチュエータ領域の内部における前記圧電アクチュエータの相互間に配設されることを特徴とする、請求項２１又は２２に記載のインクジェット記録ヘッド。

【請求項２４】　前記圧電アクチュエータの周囲を取り囲む溝を有し、該溝の幅が、全ての圧電アクチュエータの周囲で略同じに設定されることを特徴とする、請求項２１乃至２３の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項２５】　信号ラインが形成された配線基板を有し、該配線基板が、マトリクス状に２次元配列された前記圧電アクチュエータの上方を覆う位置に配置され、前記圧電アクチュエータと配線基板とがバンプを介して電気的に接続されることを特徴とする、請求項２０乃至２４の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項２６】　前記バンプが、導電性のコア材と、該コア材の外周部に被膜した接合材とによって構成されることを特徴とする、請求項２５に記載のインクジェット記録ヘッド。

【請求項２７】　前記コア材が半球状に形成されることを特徴とする、請求項２６に記載のインクジェット記録ヘッド。

【請求項２８】　前記配線基板が樹脂基材及び金属導体を含むことを特徴とする、請求項２５乃至２７の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項２９】　前記ノズルを形成する部材が樹脂フィルムで構成されていることを特徴とする、請求項１乃至２８の内の何れか１項に記載のインクジェット記録ヘッド。

【請求項３０】　請求項１乃至２９の内の何れか１項に記載のインクジェット記録ヘッドを製造する製造方法であって、

前記圧電アクチュエータを、サンドブラスト加工でパターニングすることを特徴とするインクジェット記録ヘッドの製造方法。

【請求項３１】　請求項１乃至２９の内の何れか１項に記載のインクジェット記録ヘッドを備えていることを特徴とするインクジェット記録装置。

【請求項３２】　ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインクを圧縮することにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドを駆動する駆動方法において、

前記振動要素の音響容量を$2.0\times10^{-20}m^5/N$以上に設定し、

前記振動要素に、前記圧力室の体積を収縮させる方向に電圧を印加してインク滴を吐出させる第1電圧変化プロセスと、前記圧力室の体積を膨張させる方向に電圧を印加する第２電圧変化プロセスとを含む駆動電圧波形を印加することによって１５ｐｌ以上のインク滴を吐出することを特徴とするインクジェット記録ヘッドの駆動方法。

【請求項３３】　ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインクを圧縮することにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドを駆動する駆動方法において、

前記振動要素の音響容量を$2.0\times10^{-20}m^5/N$以上且つ$5.5\times10^{-19}m^5/N$以下に設定し、

前記振動要素に、前記圧力室の体積を膨張させる方向に電圧を印加する第1電圧変化プロセスと、前記圧力室の体積を圧縮する方向に電圧を印加し前記ノズル内に該ノズルの開口径よりも小さな径の液柱を形成し該液柱の先端からインク滴を分離させて微小なインク滴の吐出を行うための第２電圧変化プロセスとを含む駆動電圧波形を印加することによって４ｐｌ以下のインク滴を吐出することを特徴とするインクジェット記録ヘッドの駆動方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、吐出するインク滴で文字や画像の記録を行うインクジェット記録ヘッド、このようなインクジェット記録ヘッドの製造方法及び駆動方法、並びにこのようなインクジェット記録ヘッドを備えたインクジェット記録装置に関する。

【０００２】

【従来の技術】近年、ノンインパクト記録方式は、記録時の騒音が極めて小さく、また高速記録が可能である点で関心を集めており、その中でも、インクジェット記録方式を用いたインクジェット式プリンタは広く普及している。このようなインクジェット式プリンタは、記録ヘッドからインク滴を飛翔させて記録紙に付着させ、文

字、図形、写真等の印字を高速で行う構成を備え、普通紙に特別の定着処理等を施すことなく記録することができる。上記インクジェット記録方式として、圧電アクチュエータ等の電気機械変換器を用い、インクが充填された圧力室に圧力波（音響波）を発生させることで、圧力室に連通するノズルからインク滴を吐出するドロップオンデマンド型インクジェット方式が知られている。

【０００３】ドロップオンデマンド型インクジェット方式を採用したインクジェット記録ヘッドが、特公昭５３－１２１３８号公報及び特開平１０－１９３５８７号公報等に記載されている。図３４は、これらの公報に記載されるインクジェット記録装置の記録ヘッドを示す断面図である。このインクジェット記録装置は、圧力室５１と、圧力室５１に連通するノズル５２と、共通流路５３を介してインクタンクからインクを導くインク供給路５４と、圧力室５１の底面に固定された振動板５５とを備えている。

【０００４】上記インクジェット記録装置では、インク滴吐出時に、圧力室５１外部に設けられた圧電アクチュエータ５６によって振動板５５を変位（撓み変形）させ、圧力室５１内で容積変化を生じさせることで、圧力室５１内に圧力波を発生させる。この圧力波によって、圧力室５１内に充填されているインクの一部が、ノズル５２を通って外部に噴射され、インク滴５７となって飛翔する。飛翔したインク滴は、記録紙等の記録媒体上に着弾して記録ドット（画素）を形成する。このような記録ドットの形成動作が画像データに基づいて繰り返し行われることにより、記録媒体上に文字や画像が記録される。

【０００５】上記ドロップオンデマンド型のインクジェット記録装置では、高速記録と高画質記録とを両立させるという要請がある。しかし、従来のインクジェット記録装置においては、高速記録と高画質記録とを両立することは極めて困難であった。例えば、高速記録の実現のために解像度を低く抑えると良好な画質が損なわれ、逆に高画質記録の実現のために解像度を高く設定すると高速記録が妨げられるというように、高速記録及び高画質記録の双方の要請はトレードオフの関係にある。

【０００６】ここで、上記インクジェット記録装置で「高速記録」及び「高画質記録」の双方を両立させるために必要な条件について説明する。つまり、「高速記録」を実現させる上では、

①記録解像度の低下、

②ノズル数の増加（ノズル密度増加）、

の二つが特に重要な条件となる。

【０００７】上記条件①の「記録解像度の低下」を実現すれば、単位面積を少ないインク滴で記録できるので、記録に要する時間を短縮することができる。例えば、３００ｄｐｉ（ドット／インチ）の記録解像度と１２００ｄｐｉの記録解像度とを比較すると、同一面積を記録するのに必要なドット数は、３００ｄｐｉの場合では１２００ｄｐｉの場合の１／１６になる。ここで、インク滴吐出の周波数（駆動周波数）が同一であると仮定すれば、３００ｄｐｉで記録する場合の方が記録速度を約１６倍に増加することが可能となる。

【０００８】しかし、記録解像度を低く設定すると画像品質が低下するので、記録解像度の低減には下限がある。人間の視覚特性から考えると、画像品質（文字や線画の品質）を損なわずに高速記録を実現するには、記録解像度を３００～６００ｄｐｉ（但し、1ドット／インチ=39.37ドット／メートル）程度の範囲内に設定することが最適である。つまり、現在一般的に使用されるインクジェット記録装置の記録解像度（７００～２４００ｄｐｉ）よりも低い記録解像度に設定した方が、記録速度を向上させる上では有利である。ただし、記録解像度を低く設定するためには、それに応じた大きなインク滴の吐出を実現する必要がある。

【０００９】すなわち、低い記録解像度で行う高速記録に対応した大きなドットを形成するためには、滴体積の大きなインク滴を吐出しなければならない。記録解像度と所要滴体積との関係は、使用するインクや記録紙種類によって多少変化するが、従来のインクジェット記録装置で用いられる一般的なインク及び記録用紙の場合には、３００～６００ｄｐｉの記録解像度で十分な記録濃度を得るためには、１５～３０ｐｌ（ピコリットル）のインク滴体積が必要となる（但し、1ピコリットル＝10^{-15}m³）。これは、記録解像度１２００ｄｐｉで必要とされるインク滴体積（約１０ｐｌ）の１．５～３倍の値である。

【００１０】また、記録速度を増加させるには、前記条件②の「ノズル数の増加」が必要である。ノズル数が多いほど、単位時間当たりに形成できるドット数が増加して、記録速度が向上する。そのため、通常のインクジェット記録装置では、前述したインク吐出機構（イジェクタ）を複数連結したマルチノズル型の記録ヘッドが多く用いられる。

【００１１】上記マルチノズル型の記録ヘッドを図３５に示す。この記録ヘッドでは、インクタンク６７が共通流路６３と連結しており、この共通流路６３に複数の圧力室６１がインク供給路（図示せず）を介して連結されている。このように、共通流路６３に対してイジェクタ６８を１次元的に配列するヘッド構造とすることにより、イジェクタ数（ノズル数）を３０～１００個程度まで増加することができる。

【００１２】また、イジェクタ数を更に増加できるヘッド構造として、イジェクタをマトリクス状に２次元配列したインクジェット記録ヘッド（以下、マトリクス状配列ヘッドと呼ぶ）が、例えば特開平１－２０８１４６号公報及び特表平１０－５０８８０８号公報等に記載されている。図３６に、これらの公報に記載されたマトリク

ス状配列ヘッドを示す。このマトリクス状配列ヘッドでは、共通流路は主流路７３と分岐流路７８とから成り、複数のイジェクタ７９は分岐流路７８の夫々に接続されている。このようなマトリクス状配列ヘッド構造は、イジェクタ数（ノズル数）の増加に極めて有利である。例えば、分岐流路７８の数を２６本とし、各分岐流路７８にイジェクタを１０個ずつ接続すると、２６０個のイジェクタを配列させることができる。なお、図３６では、イジェクタを３６個のみ表示している。

【００１３】上記のように、マトリクス状配列ヘッドはノズル数の増加に有利であるが、圧力室の配列密度を高く設定しなければ、記録ヘッド全体のサイズが増大し、ヘッド製造コストの増大、装置サイズの増大、或いは、ヘッド搬送距離が増大して記録速度が低下するなどの種々の問題を招くことになる。つまり、インクジェット記録ヘッドでノズル数を増加させるという課題は、一定の面積内に如何に多くのノズルを配置できるかであり、つまり、ノズル密度を如何に増加できるかという課題に置き換えられる。図３６に示したようなマトリクス状配列ヘッドでは、イジェクタの配列密度を増加させるために、圧力室のサイズを小さく設定することが重要な課題となる。

【００１４】一方、インクジェット記録装置で「高画像記録」を実現するためには、吐出するインク滴の径をできるだけ小さく設定することが望ましい。特に、写真画像を出力する場合には、ハイライト部（低濃度部）の粒状感が画質を大きく左右するため、極めて小さなインク滴でハイライト部を記録することが望ましい。人間の眼の分解能から、ドット径が４０μm以下になると画像の粒状感が大幅に低下し、更に３０μm以下になると個々のドットを目視認識することが困難になるため、画像品質が飛躍的に向上する。従って、画像のハイライト部では径３０μm以下の小さなドットを実現することが望ましく、そのためには２～４ｐｌ程度の微小滴の吐出を実現させなければならない。

【００１５】インクジェット記録ヘッドで微小滴吐出を行うための駆動方法が、例えば特開昭５５－１７５８９号公報に記載されている。この公報に記載の駆動方法では、吐出直前に圧力室を一旦膨張させ、ノズル開口部のメニスカスを圧力室側に引き込んだ状態からインク滴の吐出を行う。この種の駆動方法で用いられる駆動波形の一例を図３７に示す。この駆動波形は、圧力室を膨張させるための電圧変化プロセス８３と、次いで圧力室を圧縮し、インク滴の吐出を行うための電圧変化プロセス８４を含んで構成されている。

【００１６】図３８は、図３７の駆動波形を印加した際のノズル９１の開口部におけるメニスカス９２の動きを模式的に示した断面図である。図３８（ａ）に示すように、初期状態でメニスカス９２は平坦な形状をしているが、図３７に示す電圧変化プロセス８３に応答して圧力

室が膨張し始めると、メニスカス９２の中央部が周辺部よりも大きく後退することによって、メニスカス９２は、図３８（ｂ）に示すような凹曲面形状となる。

【００１７】上記凹曲面状のメニスカス９２が形成された状態から、図３７に示す電圧変化プロセス８４に応答して圧力室が圧縮を開始すると、図３８（ｃ）に示すように、メニスカス９２の中央部に細い液柱９３が形成され、更に図３８（ｄ）に示すように、液柱９３の先端部が分離してインク滴９４が形成される。このときのインク滴径は、形成された液柱９３の太さとほぼ等しく、ノズル径よりも小さい。つまり、このような駆動方法を用いることにより、ノズル径よりも小さなインク滴９４を吐出することができる。上記のように、吐出直前のメニスカス形状を制御して微小滴吐出を行う駆動方法のことを、本明細書では以下、「メニスカス制御方式」と呼ぶ。

【００１８】以上述べたように、ドロップオンデマンド型のインクジェット記録ヘッドで「高速記録」を実現するためには、低解像度記録を可能とする「大滴吐出」、及び、ノズル数増加を可能とする「ノズル密度増加」が必要である。一方、高画質記録を実現するためには、ハイライト部の粒状感低減を可能とする「小滴吐出」が必要となる。従って、「高速記録」及び「高画質記録」の双方を１つの記録ヘッドで両立させるには、「大滴吐出」、「ノズル密度増加」及び「小滴吐出」の３つの条件を同時に満足させる必要がある。

【００１９】

【発明が解決しようとする課題】しかし、高速記録を実現するための「大滴吐出」及び「ノズル密度増加」、並びに高画質記録を実現するための「小滴吐出」の全てを同時に満足させることは、従来のインクジェット記録ヘッドでは極めて困難になっている。

【００２０】また、従来のインクジェット記録ヘッドにおける別の問題点として、インク滴吐出時のメニスカスに異常な振動が発生し、インク滴の吐出現象が不安定化するという問題があった。異常なメニスカス振動が発生するメカニズムについては、従来、詳しい検討は一切なされておらず、防止方法も明らかにされていない。以下に、本発明者らによる検討結果に沿って説明する。

【００２１】図３９はレーザードップラー計測で観察したメニスカス振動の観測結果の一例を示すグラフであり、（ａ）は正常時、（ｂ）は異常時を夫々示す。本来は図３９（ａ）に示すようなメニスカス振動が得られるはずであるのに対し、実際に観察されたメニスカス振動には、図３９（ｂ）に示すように微細な振動が重畳していた。このような微細な振動がメニスカスに重畳すると、インク滴の吐出が非常に不安定になる。特に、上述したメニスカス制御方式では、メニスカスの液面干渉を利用して微小滴の吐出を行うため、メニスカス振動に上記の微細な振動が重畳すると、微小滴の吐出ができなく

なり、或いは、逆に不要なインク滴が吐出されるなど、正常な微小滴吐出が期待できなくなる。

【００２２】本発明は、上記に鑑み、ヘッドサイズの大型化やコストアップを回避しつつ、同一ノズルから所要サイズの「大滴」を吐出させ、且つ「ノズル密度増加」を実現して単位面積当たりのインク滴吐出効率を高めることができるインクジェット記録ヘッド、そのようなインクジェット記録ヘッドを搭載したインクジェット記録装置、並びに、インクジェット記録ヘッドの製造方法及び駆動方法を提供することを目的とする。

【００２３】また、本発明は、同一ノズルから所要サイズの「大滴」及び「小滴」の双方を選択的に吐出させ、高速記録と高画質記録の両立を可能とするインクジェット記録ヘッドを提供することを目的とする。本発明は更に、メニスカスの異常振動を防止し、吐出安定性の高いインクジェット記録ヘッドを実現することを目的とする。

【００２４】

【課題を解決するための手段】従来のインクジェット記録ヘッドでは、同一ノズルからの「大滴吐出」及び「小滴吐出」の実現に加えて「ノズル密度増加」という３条件を同時に満足することは極めて困難であるが、その理由を、以下に具体例を挙げて説明する。まず、「大滴吐出」について考えると、インクジェット記録ヘッドで吐出できる最大インク滴の体積は、後述するように、圧力室に発生させる体積変化量（排除体積）ΔＶにほぼ一致する（式(2)参照）。つまり、吐出するインク滴とほぼ同等の体積変化を圧力室内に発生させる必要がある。そのため、大きな滴体積を得るためには、圧電アクチュエータの駆動面積（圧力室の底面積）を増加してΔＶを増大させることが必要となる。

【００２５】例えば、圧電アクチュエータの変位量を０．１μｍとした場合に、滴体積１０ｐｌの吐出は$1\times10^{-7}m^2$程度の駆動面積で実行することができるが、滴体積を２０ｐｌに増加させようとすると、約２倍の駆動面積（$2\times10^{-7}m^2$）が必要になる。その結果、単位面積当たりのノズル数（ノズル密度）が約１／２に低減することになる。すなわち、高速記録のために低解像度記録を実現し滴体積を大きくしようとすると、圧力室のサイズが増大し、その結果として、ノズル密度が低下する。このように、「大滴吐出」と「ノズル密度増加」とはトレードオフの関係にあるので、低解像度記録とノズル数増加（ノズル密度増加）とを同時に実現することは極めて困難である。

【００２６】次に、「小滴吐出」について考える。メニスカス制御方式によって微小滴吐出を行うためには、以下に示す理由から、圧力室内に発生させる圧力波の固有周期T_cを短く設定する必要がある。つまり、図３８で説明したように、メニスカス制御方式では、初めにメニスカス９２を圧力室側に引き込み、メニスカス９２を凹曲形状にした後、メニスカス９２をノズル外側に向かって押し出すことによって細い液柱９３を形成する。本発明者らは、液柱９３の形成メカニズムについて詳細に検討を行い、その結果、形成される液柱の太さはメニスカスを押し出す際の液面速度に依存することを明らかにした。

【００２７】図３２は、メニスカス制御方式を用いた際のメニスカスの挙動を模式的に示した断面図である。すなわち、凹曲面形状のメニスカス９２に対して、外部に押し出す方向に圧力を加えると、メニスカス９２の各部は、図３２（ａ）に示すように、液面の法線方向に移動しようとする。その結果、ノズル中央部に多量のインクが集中し、この局所的な体積増加によってノズル９１の中央部に液柱９３が形成される。このとき、液面の移動速度が速いほどノズル中央部での体積増加速度も大きくなるため、非常に細い液柱９３が速い成長速度で形成される。逆に、液面の移動速度が遅い場合には、図３２（ｂ）に示すように、体積増加の速度も小さくなるため、液柱９３が太くなり、成長速度が小さくなる。

【００２８】メニスカス制御方式で吐出されるインク滴９４の滴径は、形成される液柱９３の太さとほぼ一致する。また、インク滴の飛翔速度（滴速）は、液柱９３の成長速度とほぼ一致する。従って、微小なインク滴９４を高速で飛翔させるためには、上記液面移動速度を増加させ、ノズル中央部で急激な体積増加を生じさせることが重要な条件となる。ここで、液面移動速度を支配しているのが圧力波の固有周期T_cである。つまり、インク滴吐出時におけるメニスカス９２の振動速度は圧力波の固有周期T_cに依存しており、固有周期T_cが短いほどメニスカスの振動速度、即ち、液面移動速度が増加する。従って、メニスカス制御方式によって微小滴を吐出する場合に、圧力波の固有周期T_cが短いほど有利となる。

【００２９】図３３は、メニスカス制御方式で得られる最小滴径と、圧力波の固有周期T_cとの関係を調べた結果を示すグラフである。このグラフから、固有周期が短くなるほど最小滴径が減少することが判る。得られる最小のインク滴体積は、ノズル径やインク粘度などにも依存するが、ノズル径が２０～３０μｍで、使用するインクの粘度が２～５ｃｐｓである一般的なインクジェット記録ヘッドでは、高画質記録に適した２～４ｐｌの微小滴を吐出可能とするためには、固有周期T_cを１５μｓ以下、更に望ましくは１２μｓ以下に設定する必要がある。

【００３０】しかし、固有周期T_cの減少は、先に述べた「大滴吐出」と相反関係にある。すなわち、「大滴吐出」を実現するために圧力室のサイズを大きく設定すると、圧力波の固有周期が非常に長くなる。これは、圧力波の固有周期T_cは圧力室及び振動要素（振動板＋圧電アクチュエータ）の音響容量和（c_0+c_1）に依存し、「大滴吐出」に適したサイズの大きな圧力室及び振動要

素では、固有周期T_cが長くなるためである。例えば、大滴体積が１０ｐｌ、固有周期が１０μｓのインクジェット記録ヘッドを実現することは容易であるが、大滴体積を２０ｐｌに増加しようとすると、固有周期T_cも約２倍の２０μｓ程度になってしまう。

【００３１】そこで、本発明者らは、従来はヘッド構造に関わる多数のパラメータを試行錯誤的に組み合わせて滴体積及び固有周期T_cの調整を行っていたのに対し、種々の実験結果から、撓み変形する圧電アクチュエータを用いたインクジェット記録ヘッドでは、滴体積及び固有周期T_cを支配する実質的なパラメータは振動要素の音響容量のみであることを見出し、振動要素の音響容量の適正な範囲を規定することにより、所要サイズの「大滴吐出」及び「小滴吐出」の両立と「ノズル密度増加」とを実現する本発明を発明するに至った。

【００３２】上記目的を達成するために、本発明に係るインクジェット記録ヘッドは、ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインク内に圧力波を発生させることにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドであって、前記振動要素の音響容量が、$2.0\times10^{-20}m^5/N$以上であることを特徴とする。

【００３３】振動要素の音響容量（c_0）は、振動要素の剛性を表わすパラメータであり、c_0が大きいということは、振動要素が撓み易い、即ち圧力室の大きな排除体積が発生し易いということを意味する。後述する種々の実験結果及び構造解析結果から、$2.0\times10^{-20}m^5/N$という値は、６００ｄｐｉ以下の低解像度記録に必要な１５ｐｌ以上の「大滴」の吐出を実現できるという観点から、音響容量c_0の下限値として最適な値と言える。

【００３４】例えば、圧電アクチュエータの厚さt_p、振動板の厚さt_v、及び圧力室幅Wを種々変更した例について夫々に特性評価を実施した。その結果、

音響容量$c_0 \geqq 2.0\times10^{-20}$ $[m^5/N]$

の条件下では、１５ｐｌ以上の「大滴」を吐出することができたが、

音響容量$c_0 < 2.0\times10^{-20}$ $[m^5/N]$

の条件下では、１５ｐｌ以上の「大滴」を吐出することができず、十分な画像濃度を得ることができなかった。

【００３５】つまり、本発明では、振動要素の音響容量c_0を$2.0\times10^{-20}m^5/N$以上に規定したことにより、振動要素による１5pl以上の排除体積を得て、一つのノズルから１5pl以上の大滴を吐出することができる。

【００３６】本発明の好ましいインクジェット記録ヘッドでは、振動要素の音響容量の上限を$5.5\times10^{-19}m^5/N$に設定することが望ましい。本発明者らは、音響容量c_0を$2.0\times10^{-20}m^5/N$以上の値に設定することで「大滴吐出」を実現できるが、音響容量c_0が大き過ぎると圧力室内に発生する圧力波の固有周期が増加し，「小滴吐出」が実行できなくなるという弊害が発生することを確かめた。そして、後述する種々の実験結果に基づき、音響容量c_0の上限を$5.5\times10^{-19}m^5/N$に設定することによって、上記弊害の発生を防止することに想到した。

【００３７】例えば、音響容量$c_0 > 5.5\times10^{-19}m^5/N$の条件下で吐出実験を行ったところ、１５ｐｌ以上の「大滴」は吐出できたが、４ｐｌ以下の「小滴」を吐出することはできなかった。この結果から、１５ｐｌ以上の大滴体積を確保し、且つ４ｐｌ以下の小滴体積を得るためには、振動要素の音響容量c_0を$2.0\times10^{-20}m^5/N$以上、且つ$5.5\times10^{-19}m^5/N$以下に設定するのが最適であると確認した。

【００３８】本発明の好ましいインクジェット記録ヘッドでは、前記振動要素に印加される駆動電圧波形の制御に応答して、前記ノズルから吐出するインク滴の滴体積が多段階に変化する。この場合、大滴による低解像度記録と、小滴による高画質記録を同時に実現することができるため、高速記録と高画質記録を両立できるという効果が得られる。

【００３９】また、前記ノズルから吐出するインク滴の最大滴体積が１５ｐｌ以上に設定されることが好ましい。この場合、記録解像度を６００ｄｐｉ以下に設定することが可能となるため，記録速度を増加できるという効果が得られる。１５ｐｌ以上のインク滴の吐出時に印加される駆動電圧波形は、前記圧力室の体積を収縮させる方向に電圧を印加してインク滴を吐出させる第1電圧変化プロセスと、前記圧力室の体積を膨張させる方向に電圧を印加する第２電圧変化プロセスとを少なくとも含み構成したものとすることができる。

【００４０】或いは、前記ノズルから吐出されるインク滴の最小滴体積が４ｐｌ以下であることも好ましい態様である。この場合、ハイライト部において粒状性の低い滑らかな画像記録が可能となり、高画質記録を実現できるという効果が得られる。４ｐｌ以下のインク滴の吐出時に印加される駆動電圧波形は、前記圧力室の体積を膨張させる方向に電圧を印加する第1電圧変化プロセスと、前記圧力室の体積を圧縮する方向に電圧を印加し前記ノズル内に前記ノズルの開口径よりも小さな径を有する液柱を形成し該液柱の先端からインク滴を分離させることによって微小なインク滴の吐出を行うための第２電圧変化プロセスとを少なくとも含み構成したものとすることができる。

【００４１】更に好ましくは、前記圧力室及び圧電アクチュエータの各平面形状におけるアスペクト比が夫々略1に設定される。本発明における「アスペクト比」は、振動要素の平面形状における最も長い幅と最も短い幅との比を意味する。アスペクト比が略１に設定されると、単位面積当たりの吐出効率が最大化でき、ノズル密度の

高いインクジェット記録ヘッドを実現することが可能となる。振動要素の平面形状として、略正三角形、略正方形、略正六角形、略円形の何れかを選択することができる。

【００４２】ここで、圧力室の平面寸法（平面積）を０．０９～０．５mm^2に設定し、振動板及び圧電アクチュエータの厚みを夫々、５～２０μm及び１５～４０μmに設定することが好ましい。これにより、アスペクト比が略１の圧力室を有するインクジェット記録ヘッドにおいて、振動要素の音響容量c_0を2.0×10^{-20} m^5/N以上、且つ5.5×10^{-19} m^5/N以下に設定することができ、「大滴吐出」と「小滴吐出」を両立できるという効果が得られる。

【００４３】ここで、振動要素の音響容量は圧力室の音響容量よりも大きく設定されることが好ましい。この場合、メニスカスの異常振動を抑制し、メニスカスの振動を正常化し、インク滴吐出の安定性を向上できるという効果を得ることができる。

【００４４】また、前記圧力室内で発生する圧力波の固有周期をT_c、前記振動要素及び圧力室の合成音響容量をc_c、前記振動要素のイナータンスをm_0とすると、次式

$$m_0 < 2.5\times10^{-4}\, T_c{}^2 / c_c \ [kg/m^4]$$

を満足することも好ましい態様である。これにより、インクジェット記録ヘッドに内在する振動系の励起を抑制することができ、上記メニスカス異常振動の影響を更に抑制でき、吐出安定性に優れたインクジェット記録ヘッドを実現することが可能となる。

【００４５】前記圧力室の幅をW、前記圧力室の中心と前記圧電アクチュエータの駆動部の中心との位置ずれ量をδ、前記圧電アクチュエータの幅をW_pとすると、次式

$$W_p \leqq (W-2\delta) \text{ 又は } W_p \geqq (W+2\delta)$$

を満足することが好ましい。この場合、圧電アクチュエータ端部の支持条件が常に一定となり、圧電アクチュエータの位置ずれに対するロバスト性（鈍感さ）が向上する。

【００４６】また、前記圧力室の幅をW、前記圧力室の中心と前記圧電アクチュエータの駆動部の中心との位置ずれ量をδ、前記圧電アクチュエータの幅をW_pとすると、次式

$$0.9(W-2\delta) \leqq W_p \leqq (W-2\delta)$$

を満足することも好ましい態様である。これにより、圧電アクチュエータと圧力室との間に接合位置ズレが発生した場合でも、吐出効率に大きな変化が生じることを防止でき、更に高い吐出効率を確保することが可能となる。

【００４７】前記ノズルから吐出したインク滴が、６００ｄｐｉ以下の記録解像度で記録媒体上に着弾されることが好ましい。この場合、記録に必要となるドットの数を少なくでき、高速記録に有利になると同時に、記録される文字等の品質も確保できるため、高速記録と高画質記録の両立が可能になるという効果が得られる。また、前記圧力室内に発生する圧力波の固有周期T_cが１５μs以下に設定されることも好ましい態様である。この場合、メニスカス制御方式によって径の小さなインク滴を吐出することが可能となり、写真画像等の出力において、画像品質を向上できるという効果が得られる。

【００４８】また、前記圧電アクチュエータが、前記圧力室に相当する領域に配置された駆動部と、前記圧力室の外壁に相当する領域に配置された電極パッド部と、前記駆動部及び前記電極パッド部の双方を連結するブリッジ部とを備えることも好ましい態様である。これにより、圧電アクチュエータの変形が電極パッド部によって妨げられる現象を抑制でき、吐出効率の高いインクジェット記録ヘッドを実現することが可能となる。前記ブリッジ部が、前記駆動部の中心から離れた位置に連結されると、前記駆動部の変形に対する拘束力を最小化でき、ヘッドの吐出効率を増加できるという効果を得ることができる。

【００４９】また、前記ノズルがマトリクス状に２次元配列されていることも好ましい態様である。この場合、ヘッド内のノズル数を増加することが可能となるため、記録速度を大幅に増加できるという効果が得られる。

【００５０】好ましくは、圧電アクチュエータが複数配列された圧電アクチュエータ領域の外周部を取り囲むようにダミーパターンが配設される。これにより、圧電アクチュエータの加工をサンドブラスト加工法によって行う際に、サイドエッチングに起因した加工精度の悪化を防止することができ、吐出特性の均一性が高いインクジェット記録ヘッドを実現できるという効果が得られる。ダミーパターンは、圧電アクチュエータ領域の内部における圧電アクチュエータの相互間にも配設することができる。この場合、上記のサイドエッチングの影響を更に抑制できるという効果が得られる。

【００５１】本発明の好ましいインクジェット記録ヘッドでは、信号ラインが形成された配線基板を有し、該配線基板が、２次元的にマトリクス配置された前記圧電アクチュエータの上方を覆う位置に配置され、前記圧電アクチュエータと前記配線基板とがバンプを介して電気的に接続されている。これにより、高密度配列したマトリクス状配列ヘッドにおいても個々の圧電アクチュエータに対して確実な電気接続が可能となる。つまり、信号線を振動要素とは別の平面状に配置できるので、信号線の配置が圧力室の高密度配列を損なうことがなく、圧力室の高密度配列が可能となる。

【００５２】また、前記バンプが、導電性のコア材と、該コア材の外周部に被膜した接合材とによって構成されていることが好ましい。この場合、電気接続後において圧電アクチュエータと配線基板との間に間隙を形成する

ことが可能となるため、圧電アクチュエータと配線基板との接触に起因する圧電アクチュエータの特性不良が防止でき、信頼性の高いインクジェット記録ヘッドを実現できる。更に、前記コア材が半球状に形成されていることが好ましい。この場合、圧電アクチュエータとバンプとの接触状態を均一化することができ、安定した電気接続が可能になると同時に、電気接続時における圧電アクチュエ－タの破壊を防止することができるという効果が得られる。前記配線基板は、樹脂基材及び金属導体を含むことが好ましい。この場合、圧電アクチュエータとバンプとの接触状態をより一層均一化することができる。

【００５３】本発明に係るインクジェット記録ヘッドの製造方法は、前記インクジェット記録ヘッドを製造する製造方法であって、前記圧電アクチュエータのサンドブラスト加工でパターニングすることを特徴とする。

【００５４】本発明に係るインクジェット記録ヘッドの製造方法では、圧電アクチュエータのパターニングをサンドブラスト加工で行うので、吐出効率の最大化及び電気接続に適した複雑形状の圧電アクチュエータを、高い寸法精度及び低い製造コストで実現することができる。

【００５５】本発明に係るインクジェット記録装置は、前記インクジェット記録ヘッドを備えていることを特徴とする。このようなインクジェット記録装置によると、高い記録速度と高い画品質を両立可能なインクジェット記録装置を実現することができる。

【００５６】本発明に係る第１視点のインクジェット記録ヘッドの駆動方法は、ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインクを圧縮することにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドを駆動する駆動方法において、前記振動要素の音響容量を$2.0\times10^{-20}m^5/N$以上に設定し、前記振動要素に、前記圧力室の体積を収縮させる方向に電圧を印加してインク滴を吐出させる第1電圧変化プロセスと、前記圧力室の体積を膨張させる方向に電圧を印加する第２電圧変化プロセスとを含む駆動電圧波形を印加することによって１５ｐｌ以上のインク滴を吐出することを特徴とする。

【００５７】本発明の第１視点のインクジェット記録ヘッドの駆動方法では、６００ｄｐｉ以下の低解像度記録に必要となる滴体積の大きなインク滴の吐出を良好に実現できるという効果が得られる。

【００５８】本発明に係る第２視点のインクジェット記録ヘッドの駆動方法は、ノズルと、該ノズルに連通する圧力室と、該圧力室の壁面の一部を形成する振動板と、前記圧力室に対応するように前記振動板と接合された圧電アクチュエータとを備え、前記振動板と前記圧電アクチュエータとから成る振動要素が変形して前記圧力室内に充填されたインクを圧縮することにより、前記ノズルからインク滴が吐出するインクジェット記録ヘッドを駆動する駆動方法において、前記振動要素の音響容量を$2.0\times10^{-20}m^5/N$以上且つ$5.5\times10^{-19}m^5/N$以下に設定し、前記振動要素に、前記圧力室の体積を膨張させる方向に電圧を印加する第1電圧変化プロセスと、前記圧力室の体積を圧縮する方向に電圧を印加し前記ノズル内に該ノズルの開口径よりも小さな径の液柱を形成し該液柱の先端からインク滴を分離させて微小なインク滴の吐出を行うための第２電圧変化プロセスとを含む駆動電圧波形を印加することによって４ｐｌ以下のインク滴を吐出することを特徴とする。

【００５９】本発明の第２視点のインクジェット記録ヘッドの駆動方法では、粒状性の低い高い画品質をもった画像記録を実現できるという効果が得られる。

【００６０】

【発明の実施の形態】本発明に係るインクジェット記録ヘッドの実施形態例を説明するに先立ち、先ず、振動要素の動作特性とインク滴体積との関係について説明する。つまり、振動要素は、現象的に見た際に物理的な振動を発生するので、機械系であるが、インクジェット記録ヘッドは、機械系以外にも、インク流路の音響系や、駆動回路の電気系を混在して備えている。これら３系は、その微分方程式記述が同一形式であるので、相互に等価変換することができる。従って、ここでは全て音響系に統一し、記録ヘッドの動作を一つの音響回路として考える。

【００６１】振動要素（振動板＋圧電アクチュエータ）の動作特性は、機械系では質量［kg］、コンプライアンス［m/N］、及び減衰［Ns/m］の３つのパラメータだけで表わすことができる。これらを音響系に等価変換すると、振動要素の動作特性はイナータンスm_0［kg/m⁴］、音響容量c_0［m⁵/N］、及び音響抵抗r_0［Ns/m⁵］の３つのパラメータだけで表わすことができる。

【００６２】上記音響系パラメータを用いると、一つの振動要素は図１に示す等価回路（音響回路）として表わすことができる。ここで、ψは圧力［Ｐａ］を表わす。また、図２（ａ）は、振動要素と流路系を連結した等価回路であり、図３４に示したインクジェット記録ヘッドを等価回路に置き換えたものである。

【００６３】ここで、ｕは体積速度［m^3／ｓ］、添字の０は振動要素、１は圧力室、２はインク供給路、３はノズルをそれぞれ意味している。この回路を、回路シミュレータ等を用いて解析し、ノズル部の体積速度u_3の変化を調べることによって、インク滴体積、滴速、圧力波の固有周期などのヘッド特性を求めることができる。

【００６４】図３（ａ）～（ｃ）は夫々、振動要素の音響容量c_0、イナータンスm_0、及び音響抵抗r_0と排除体積ΔＶの関係を、図２（ａ）の等価回路を用いて調べた結果である。なお、排除体積ΔＶは、後述するように

滴体積ｑとほぼ一致するパラメータである。この結果から、m_0とｒ$_0$は排除体積ΔＶ（滴体積ｑ）にはほとんど影響を及ぼさないのに対し、ｃ$_0$はΔＶに大きく影響し、ｃ$_0$が大きいほどΔＶが増加する傾向が明らかになった。つまり、振動要素の音響容量ｃ$_0$、イナータンスm_0、及び音響抵抗ｒ$_0$のうち、吐出特性（滴体積ｑ）に影響するのはｃ$_0$のみであることが明らかになった。

【００６５】振動要素のイナータンスm_0及び音響抵抗ｒ$_0$が吐出特性（滴体積）に大きな影響を及ぼさず、また、ノズルの音響容量ｃ$_3$も振動要素の音響容量ｃ$_0$及び圧力室の音響容量ｃ$_1$に対して無視することができることから、図２（ａ）の回路は、図２（ｂ）のように簡略化できる。ここで、ノズル及び供給路におけるイナータンス及び音響抵抗に、

m_2＝ｋ・m_3、ｒ$_2$＝ｋ・ｒ$_3$

の関係が成り立つと仮定し、ステップ関数的な圧力ψを入力した場合について理論解析を行うと、ノズル部での体積速度ｕ$_3$は次式のように表わされる。

【００６６】

【式１】

$$u_3(t)=\frac{c_0\,\psi}{cm_3\,E_c}\exp(-D_c\cdot t)\sin(E_c\cdot t) \qquad (1)$$

$$c=c_0+c_1$$

$$E_c=\sqrt{\frac{1+\frac{1}{k}}{cm_3}-D_c^2}$$

$$D_c=\frac{r_3}{2m_3}$$

【００６７】ノズルから吐出されるインク滴（大滴）の体積ｑ［m^3］は、図３９（ａ）に示した斜線部の面積にほぼ等しいため、ｑは次式によって表わされる。

【００６８】

【式２】

$$q=\int_0^{tm}u_3\,dt \qquad (2)$$

$$\approx 2\frac{m_2}{m_2+m_3}\cdot V\cdot\phi\cdot c_0$$

$$=2\frac{m_2}{m_2+m_3}\cdot\Delta V$$

【００６９】φ［Ｐａ／Ｖ］は、電気音響変換係数（＝ψ／Ｖ）であり、単位電圧当たりに発生する圧力の大きさを表わすパラメータである。撓み変形する圧電アクチュエータを用いたインクジェット記録ヘッドでは、この電気音響変換係数φは、滴体積（吐出効率）を左右する極めて重要なパラメータである。しかしながら、ヘッド構造とφとの関係については、過去に詳しく調べられた例はない。そこで本発明者らは、有限要素法を用いた構造解析によって、ヘッド構造とφとの関係について調査を行った。

【００７０】構造解析によってφを求めるには、次のような方法を用いればよい。まず、振動要素をモデル化し、印加電圧Ｖを印加した際の振動要素の変形状態を求める。次に、振動要素に圧力を加え、振動要素の変形量をゼロに戻すために必要な圧力ｐを求める。このｐの値をもとに、φ＝ｐ／Ｖとしてφの値を求める。また、同様に振動要素の音響容量ｃ$_0$は、圧力ｐを加えて振動要素を変形させたときに発生する排除体積ΔＶを求めることにより、ｃ$_0$＝ΔＶ／ｐとして算出する。

【００７１】図４（ａ）は、ヘッド構造に関わる各パラメータを広い範囲で変化させて構造解析を行い、ｃ$_0$とφの値を求めた結果を示すグラフである。具体的には、圧力室及び圧電アクチュエータの平面視における面積を９×１０$^{-8}$～１×１０$^{-6}$m^{2}の範囲で、圧力室及び圧電アクチュエータ夫々の平面形状におけるアスペクト比を１～２０の範囲で変化させた。また、振動板厚を、ステンレス等の金属板では５～２０μｍの範囲で、ポリイミドフィルムでは２０～１００μｍの範囲で変化させた。更に、圧電アクチュエータ厚を１０～５０μｍの範囲で、圧電定数を１×１０$^{-10}$～３×１０$^{-10}$ｍ／Ｖの範囲で夫々変化させ、様々な組み合わせに対して構造解析を行い、φとｃ$_0$の値を求めた。その結果、音響容量ｃ$_0$は1×１０$^{-21}$～５×１０$^{-18}$m^5／Ｎ、φは４×１０^3～４×１０^{4}Ｐａ／Ｖの範囲で変化することが判明した。

【００７２】上記解析結果に基づいてφ・ｃ$_0$（単位電圧当たりの滴体積を決定するパラメータ；前記式（２）参照）とｃ$_0$との関係を調べた結果を図４（ｂ）に示す。この結果から、ｃ$_0$とφ・ｃ$_0$との関係は、グラフ中の斜線部の範囲内に分散するが、一般論として、大きな滴体積（大きなφ・ｃ$_0$）を得るためには、

ｃ$_0$≧２．０×１０$^{-20}$［m^5／N］

と設定する必要があることが明らかになった。

【００７３】すなわち、撓み変形する圧電アクチュエータを利用したインクジェット記録ヘッドにおいて大きな滴体積（吐出効率）を確保するためには、

ｃ$_0$≧２．０×１０$^{-20}$［m^5／N］

が重要な条件となる。音響容量ｃ$_0$は振動要素の剛性を表わすパラメータであり、ｃ$_0$が大きいということは、振動要素が撓み易い、即ち大きな排除体積ΔＶを発生し易いということを意味している。また、２．０×１０$^{-20}$m^5／Ｎという値は、以下に述べるように、６００ｄｐｉ以下の低解像度記録を可能とする１５ｐｌ以上の大滴を得るという観点からも、音響容量ｃ$_0$の下限値として適した値と言える。

【００７４】実際のインクジェット記録ヘッドを作製する上で最も適切、且つ一般的な条件として、振動板を金属材料（ステンレス、ニッケル等）で構成し、圧電定数

を約3×10^{-10}m／Ｖとすると、c_0と$\phi\cdot c_0$との関係は、図５及び図６に示すようになる。

【００７５】図５はc_0と$\phi\cdot c_0$との関係を示す別のグラフ、図６は図５の一部を拡大したグラフである。つまり、振動板材質や圧電定数を固定すると、振動板厚、圧電アクチュエータ厚、アスペクト比などの値を変えても、c_0と$\phi\cdot c_0$との関係は、ほぼ一本の曲線上にプロットされることが明らかになった。これは即ち、滴体積ｑを支配するパラメータのうち、ϕはc_0の関数として扱えることを意味している。

【００７６】前記式（２）におけるm_2及びm_3は、一般的なインクジェット記録ヘッドでは、後述するように$m_2\fallingdotseq m_3$と設定される。また、印加電圧Ｖも駆動回路や電源コストを考えると、４０Ｖ程度が上限となる。従って、式（２）のパラメータのうち、m_2／（m_2+m_3）及び印加電圧Ｖは、実際には任意に変えることのできないパラメータであり、また、ϕはc_0に依存するパラメータであるため、滴体積ｑを支配しているパラメータは実質的にc_0のみであると言える。

【００７７】そこで、図６の結果から１５ｐｌ以上の滴体積を得るのに必要なc_0を求めてみる。上記のように、m_2／（m_2+m_3）≒１／２、Ｖ≦４０［Ｖ］と置くことができるので、１５ｐｌ以上の滴体積を確保するためには、$\phi\cdot c_0$を4×10^{-16}m^3／Ｖ以上に設定する必要がある。これを、図６のグラフに当てはめると、$c_0\geqq2.0\times10^{-20}$m^5／Ｎの条件となる。つまり、撓み変形する圧電アクチュエータを利用したインクジェット記録ヘッドで低解像度記録に適した１５ｐｌ以上の滴体積を得るという観点からも、$c_0\geqq2.0\times10^{-20}$m^5／Ｎは重要な条件となる。

【００７８】以上述べたように、撓み変形する圧電アクチュエータを用いたインクジェット記録ヘッドにおいて、滴体積を支配する実質的なパラメータがc_0のみであることを見出し、c_0の適正な下限値を規定した点が、本発明の特徴の一つである。従来は、ヘッド構造に関わる多数のパラメータを試行錯誤的に組み合わせて滴体積の調整を行っていたのに対し、上記のように支配パラメータをc_0の一つだけに整理し、その最適範囲を明らかにしたことは、ヘッドの最適化設計を行う上で極めて有効である。

【００７９】次に、「大滴吐出」と「ノズル密度増加」とを両立させる圧力室形状について考える。上述したように、滴体積を実質的に支配しているパラメータがc_0だけであることから、「大滴吐出」と「ノズル密度増加」とを両立させるためには、単位面積当たりのc_0を最大化することが重要である。

【００８０】音響容量c_0は振動要素の形状に大きく依存する。そこで、単位面積当たりのc_0を最大化できる振動要素形状について調査を行った。図７は、四角形の圧力室に関し、面積が同一でアスペクト比（縦横比）が異なる各形状に対してc_0を求めた結果である。図７から、圧力室の平面形状のアスペクト比が１に近づくほど、即ち、正方形に近い形状であるほど音響容量c_0は増加することが判る。つまり、アスペクト比が１に近い平面形状の圧力室を用いれば、小さい占有面積で大きな音響容量c_0を得ることが可能となり、ノズル密度の向上に有利となる。

【００８１】図７に示した結果から、単位面積当たりの吐出効率を高く設定するためには、圧力室のアスペクト比を少なくとも０．３～３の間に設定することが必要である。更に好ましいのはアスペクト比を０．８～１．２の間に設定することである。この場合、アスペクト比＝１の最適条件と比較して吐出効率の低下を３０％以下に納めることができる。

【００８２】ここで、「アスペクト比」とは、アスペクト比の定義を説明する図８（ａ）～（ｄ）に示すように、圧力室の平面形状における最も長い幅（Ａ）と最も短い幅（Ｂ）との比（Ｂ／Ａ）を示す値を意味する。また、圧力室の平面形状のアスペクト比を略１に設定した場合、通常、振動要素のアスペクト比も略１となる。すなわち、振動要素は振動板と圧電アクチュエータの駆動部（後述）から構成されており、圧電アクチュエータの駆動部は圧力室の平面形状とほぼ一致する形状とされるため、振動要素のアスペクト比も略１となる。

【００８３】図７は四角形の圧力室について調査した結果であるが、それ以外の三角形、五角形及び六角形を含む多角形や、楕円形についても、

アスペクト比＝１

でc_0が最大になるという同様の結果が得られている。従って、

アスペクト比＝１

が最適であるという結論は、四角形以外の他の形状の圧力室についても一般的に当てはめることができる。

【００８４】次に、図３９（ｂ）に示した異常なメニスカス振動の原因について述べる。図９は、図２（ａ）の等価電気回路の周波数応答を調べた結果を示すグラフである。このグラフで、１３０ｋＨｚ及び１．３ＭＨｚにピークが存在していることから、本回路は二つの共振周波数を有していることが判る。図１０は、図２（ａ）の等価電気回路を書き換えた、１個のイジェクタの等価電気回路を示す回路図である。回路をこのように書き換えた場合、本回路にはＡ、Ｂという二つの振動系が含まれていることが判る。

【００８５】すなわち、図９に見られた二つの共振周波数は、振動系Ａ及びＢの各共振周波数に対応していると考えることができる。インク滴吐出に用いられる本来のメニスカス振動は振動系Ａによって発生し、これに振動系Ｂによる周期の短い振動が重畳していると考えれば、図３９（ｂ）のようなメニスカス振動の発生が理解できる。振動系Ａの固有周期T_cは、次式のように表わされ

る。

【００８６】

【式３】

$$T_c=2\pi\sqrt{\frac{m_2 m_3}{m_2+m_3}\cdot(c_0+c_1)} \qquad (3)$$

【００８７】振動系Ａでは、c_0とc_1とが並列接続になっている点が特徴的であり、そのため、メニスカス振動の固有周期T_cは

$c\ (=c_0+c_1)$

によって支配される。一方、振動系Ｂの固有周期T_Bは、次式のように表わされる。

【００８８】

【式４】

$$T_B=2\pi\sqrt{m_0\cdot c_c} \qquad (4)$$

【００８９】式４におけるc_cは、振動要素の音響容量c_0と圧力室の音響容量c_1を直列接続した際の合成音響容量であり、次式で表わされる。

【００９０】

【式５】

$$c_c=\frac{1}{\frac{1}{c_0}+\frac{1}{c_1}} \qquad (5)$$

【００９１】すなわち、c_0とc_1とが直列接続された合成音響容量c_cによって支配されるという点が、振動系Ｂの特徴である。この振動系Ｂは、特開平6-171080号公報等に記載される縦振動型圧電アクチュエータを用いたインクジェット記録ヘッドで見られる振動要素自体の固有振動とは異なるものである。振動系Ｂは、振動要素自体の固有振動系ではなく、あくまでも振動要素と流路系（圧力室）とを連結することによって形成される振動系の一つである。

【００９２】上記のように、撓み変形する圧電アクチュエータでは、記録ヘッド内に二つの振動系が存在するので、正常なメニスカス振動を得るには、上記振動系Ｂの影響を抑制することが必要である。この実現のためには、振動系Ｂの振動振幅を小さくする（条件１）、及び、$T_B \ll T_c$とする（条件２）の二つの条件を満たす必要がある。以下、二つの条件を満たすための具体的な対策について述べる。

【００９３】ステップ関数的な圧力ψを入力したときの振動系Ｂの応答は次式のように表すことができる。

【００９４】

【式６】

$$u_B(t)=\frac{\psi}{m_0 E_0}\exp(-D_B\cdot t)\sin(E_B\cdot t) \qquad (6)$$

$$\approx \psi\cdot\sqrt{\frac{c_c}{m_0}}\exp(-D_B\cdot t)\sin(E_B\cdot t)$$

$$E_B=\sqrt{\frac{1}{c_c m_0}-D_B^2}$$

$$D_B=\frac{r_0}{2m_0}$$

【００９５】すなわち、振動系Ｂによって生じる体積速度u_Bの振幅はc_cの１／２乗に比例するため、振動系Ｂの振幅を小さくするためには（条件１）、c_cを小さく設定する必要がある。ただし、本来のメニスカス振動（振動系Ａ）の振幅や固有周期に影響を及ぼさないようにするため、

$c\ (=c_0+c_1)$

は一定の条件下でc_cを最小化する必要がある。

【００９６】図１１は、c_0の値によるc_cの変化を示すグラフである。このグラフでは、$c_0+c_1=10$として計算した。このグラフから、c_cを小さくするためにはc_0とc_1とをアンバランス（不均衡）に設定、つまり、$c_0>c_1$又は$c_0<c_1$と設定すればよいことが分かる。ただし、c_0を小さくすると、前述したように滴体積qが減少するのでので、滴体積の確保、及び振動系Ｂの振幅減少の双方を両立させるために、$c_0>c_1$とする必要がある。

【００９７】次式に示されるように、圧力室の音響容量c_1は、圧力室の体積W_1に比例する。ただし、κはインクの体積弾性率［Ｐａ］、αは補正係数（$0<\alpha<1$）である。

【００９８】

【式７】

$$c_1=\frac{W_1}{\kappa\cdot\alpha} \qquad (7)$$

【００９９】１５ｐｌ以上の滴体積を吐出するインクジェット記録ヘッドでは、圧力室の底面積の下限は約$9\times10^{-8}m^2$であり、圧力室高さの下限は、インクの流動性を確保するために５０μｍ程度にされる。そのため、圧力室の音響容量c_1は、$2\times10^{-20}m^5/N$以上の値となる。従って、振動系Ｂの振動振幅を小さく抑制するには、$c_0\geqq 2\times10^{-20}m^5/N$と設定する必要がある。すなわち、振動系Ｂの影響を防止し、安定したメニスカス振動を得るという観点からも、

$c_0\geqq 2\times10^{-20}$ ［m^5/N］

は重要な条件となる。

【０１００】また、振動系Ｂが振動系Ａに及ぼす影響を低減するためには、$T_B \ll T_c$とすること（条件２）も重要である。すなわち、振動系Ｂの固有周期T_BをT_cに比

べて十分小さく設定できれば、メニスカス挙動への実質的な影響を小さく抑えることが可能となる。振動系Ｂの固有周期T_Bは式（４）で表わされることから、T_Bを小さくするためには、c_c及びm_0を小さくする必要がある。

【０１０１】流体シミュレーション及び実際の吐出実験の結果から、正常なインク滴吐出を行うためには、$T_B < T_c/10$とすることが望ましいことが明らかになった。従って、下式の条件が成立するようにm_0を設定する必要がある。

【０１０２】

【式８】

$$m_0 < \frac{1}{c_c}\left(\frac{T_c}{20\pi}\right)^2 = 2.53\times10^{-4}\,\frac{T_c^2}{c_c} \qquad (8)$$

【０１０３】以上述べたように、図３９（ｂ）に示したメニスカスの異常振動が、ヘッド内に含有される第２の振動系（振動系Ｂ）の影響によるものであることを明らかにし、更に、振動系Ｂによる悪影響を抑制できる条件を明らかにした点も、本発明の特徴の一つである。なお、撓み変形する圧電アクチュエータを用いたインクジェット記録ヘッドにおいて上記振動系Ｂの存在及びその影響について言及した開示例は、本発明者らが知る限り存在していない。

【０１０４】これまで述べてきたように、「大滴吐出」及び「メニスカス振動の正常化（振動系Ｂの影響抑制）」の観点からは、c_0は大きいほど有利であることが判った。しかしその一方で、式（３）から判るように、c_0を大きくすると固有周期Ｔｃも増加してしまう。前述したように、メニスカス制御方式によって微小滴を吐出するためには、固有周期T_cは一定以下に抑える必要がある。具体的には、T_cを１５μｓ以下に設定する必要がある。そこで次に、固有周期T_cを小さく設定するという観点から、c_0の上限値について考える。

【０１０５】式（３）に示されるように、T_cは$m_2\cdot m_3/(m_2+m_3)$の１／２乗に比例する。イナータンスｍは、次式のように管路断面積Ａ［m_2］及び管路長さｌ［m］によって決まるパラメータである。ただし、ρはインクの密度［ｋｇ／m^3］である。

【０１０６】

【式９】

$$m = \frac{\rho l}{A} \qquad (9)$$

【０１０７】一般的なインクジェット記録ヘッドでは、ノズルのイナータンスm_3と供給路のイナータンスm_2とがほぼ等しく設定される。なぜならば、$m_3 \gg m_2$であると、滴吐出後のインク補充速度であるリフィル速度は大きくなるが、吐出効率が低下することになる（式２を参照）。一方、$m_3 \ll m_2$であると、吐出効率は増加するが、リフィル速度が低下することになる。従って、一般的なインクジェット記録ヘッドでは、吐出効率確保とリフィル速度増加との両立を図るため、$m_2 \fallingdotseq m_3$と設定される。

【０１０８】また、実際のノズル形状、つまり、開口径３０μm以下、長さ２０μm以上、テーパー角１５°以下としたノズル形状から考えると、m_3は2×10^7ｋｇ／m^4以上の値となる。従って、$m_2\cdot m_3/(m_2+m_3)$は約1×10^7ｋｇ／m^4が下限値となる。

【０１０９】また、前述したように、圧力室の音響容量c_1は約$2\times10^{-20}m^5$／Ｎが下限となる。従って、式（３）から、１５μｓ以下の固有周期T_cを得るためには、音響容量c_0を$5.5\times10^{-19}m^5$／Ｎ以下に設定する必要がある。つまり、固有周期T_cについても、滴体積ｑの場合と同様、いくつかの決定因子（パラメータ）が存在しているが、T_cを小さく設定しようとした場合には、実質的にc_0のみが支配パラメータとなる。そして、小滴吐出に適した１５μｓ以下の固有周期T_cを得るためには、音響容量c_0を$5.5\times10^{-19}m^5$／Ｎ以下に設定することが必要条件となる。

【０１１０】以上の内容をまとめると、撓み変形する圧電アクチュエータを用いたインクジェット記録ヘッドでは、滴体積ｑ及び固有周期T_cは、振動要素の音響容量c_0によって支配され、その他のパラメータの上限／下限値を考慮すると、c_0に最適範囲が存在する。すなわち、音響容量c_0を次式の条件を満足するように設定することにより、「大滴吐出」と「小滴吐出」とを両立させることができる。

$$2.0\times10^{-20} \leqq c_0 \leqq 5.5\times10^{-19}\ [m^5/N] \qquad (10)$$

【０１１１】また、$c_0 > c_1$及び式（８）の条件を満足することにより、ヘッド内に形成される第２の振動系（振動系Ｂ）の影響を抑制することができ、吐出安定性及び信頼性に優れたインクジェット記録ヘッドを実現することができる。更に、圧力室のアスペクト比を略１に設定することにより、単位面積当たりのc_0を最大化でき、ノズル密度の高いインクジェット記録ヘッドを実現することができる。

【０１１２】第１実施形態例

以下、図面を参照し、本発明に係る第１実施形態例に基づいて本発明を更に詳細に説明する。本実施形態例では、$c \geqq 2.0\times10^{-20}m^5/N$の条件を満たす振動要素の具体的構成を調査、試作し、インク滴吐出実験を行った結果として示す。図１２は、本実施形態例のインクジェット記録ヘッドを展開した状態で示す斜視図である。

【０１１３】本インクジェット記録ヘッドは、マトリクス状（行列状）に複数のノズル１３が形成されたノズルプレート２９上に、インクプールプレート３８と、インク供給プレート３９と、複数の圧力室１４が形成された圧力室プレート４０と、圧力室１４の壁面の一部を成す

振動板４１とがこの順に接合されている。振動板４１には、各圧力室１４に対向するように複数の圧電アクチュエータ１６が接合されている。

【０１１４】図１３は、図１２の構成を一部透視した状態で示す平面図である。本実施形態例のノズル配置は、８行×８列のマトリクス状の配列とされている。行方向でのノズルピッチは、解像度600dpiに対応する42.3μmである。従って、行ピッチは、42.3μm×8列＝338μmであり、圧力室１４の行方向での幅は、そのピッチに収まる328μmとされる。

【０１１５】また、列ピッチも338μmとされ、圧力室１４の列方向での幅はそのピッチに収まる328μmとされる。つまり、圧力室１４の平面形状は正方形である。振動要素の平面形状も、圧力室１４の平面形状と同一であり、その平面積は0.108mm²と、従来の構造よりも大幅に面積が小さくされている。振動要素の平面寸法が決まると、音響容量を決める構造パラメータは、その構成部材である振動板４１と圧電アクチュエータ１６の材質と厚さのみである。ここでは、振動板４１の材質をステンレス鋼（SUS304）、圧電アクチュエータ１６の材質をチタン酸ジルコン酸鉛系セラミクスに決めた。従って、残る構造パラメータは、これら二つの部材の厚さである。

【０１１６】厚さを決めるために、まず二つの部材の厚さと音響容量c_0との関係を調査した。音響容量c_0の算出には有限要素解析を用い、構造モデル化した振動要素に均一圧力pを印加した際の排除体積ΔVを計算し、

$c_0 = \Delta V / p$

とした。

【０１１７】上記結果をまとめたものを図１４のグラフに示す。グラフでは、横軸に振動板４１の厚さを、縦軸に圧電アクチュエータ１６の厚さをとり、それらの組み合わせに対する音響容量c_0を解析調査し、

$c_0 \geqq 2.0 \times 10^{-20}$ [m⁵/N]

の条件を満たす組み合わせの領域を塗り潰して表した。その領域内のどの厚さ組み合わせでも、振動要素の排除体積は15pl以上を得ることができる。従って、これを用いたインクジェット記録ヘッドでは15pl以上のインク滴を吐出することができる。

【０１１８】本実施形態例では、その解の一つとして、振動板４１の厚さを５μm、圧電アクチュエータ１６の厚さを１０μmにした試作を行い、更に、インク流路と組み合わせてインク滴吐出実験を行った。その具体例を以下に示す。

【０１１９】つまり、ノズルプレート２９、インクプールプレート３８、供給路プレート３９、圧力室プレート４０、及び振動板４１は、その外形寸法が全て同一であり、ヘッド走査方向での幅が４mm、ヘッド走査方向と直交する方向での幅が４mmとされている。また、材質も全てステンレス鋼（SUS304）とされている。

【０１２０】ノズルプレート２９は、厚さが５０μmであり、上述のレイアウトに従い、直径２５μmのマトリクス状のノズル１３がプレス加工で貫通・形成されている。インクプールプレート３８の厚さは200μmであり、ノズル１３に連通する直径２８μmの連通孔３８ａがプレス加工で形成され、インクプール３８ｂがエッチング加工で形成されている。

【０１２１】供給路プレート３９は、厚さが５０μmであり、プレス加工によって、ノズル１３に連通する直径２８μmの連通孔３９ａと、インクプール３８ｂに連通する直径２５μmのインク供給路３９ｂとが形成されている。圧力室プレート４０は、厚さが８０μmであり、上述の平面形状に従い、エッチング加工で、複数の圧力室１４が形成されている。振動板４１は、既に述べたように厚さが５μmとされ、導電性を有し、圧電アクチュエータ１６の駆動電圧波形を印加するための共通電極としても機能する。以上の５種類のプレートには、相互に位置決め接合するためのアライメントマーカ（図示せず）が付与されている。

【０１２２】圧電アクチュエータ１６は、既に述べたように厚さが１０μmとされる。各圧電アクチュエータ１６は、各圧力室１４に対応して振動板４１上に個別に設けられており、その平面形状は圧力室１４の外形と同一である。

【０１２３】圧電アクチュエータ１６の両面には、電極膜が夫々形成されている。電気配線パターンを有するフレキシブルケーブル（図示せず）と、圧電アクチュエータ１６の自由表面側の電極膜（個別電極）とは、ワイヤボンディングを介して電気的に接続されている。

【０１２４】次に、本実施形態例のインクジェット記録ヘッドの製造方法について説明する。図１５は、この製造方法を示す斜視図であり、（ａ）～（ｄ）は各工程を段階的に示す。まず、図１５（ａ）に示すように、円柱状の圧電材料ブロック（図示せず）にラップ研磨加工を施し、圧電材料プレート４２を作製する。研磨加工は、厚さが圧電アクチュエータ１６の設計厚さと同じになるように行う。この圧電材料プレート４２の両面に夫々、スパッタリングで電極膜４３を形成する。本実施形態例では、電極膜４３の電極材料として金（Au）を用いた。

【０１２５】次いで、図１５（ｂ）に示すように、高温時に粘着力が無くなる性質を有する粘着発泡テープ４４を介して、スパッタリング済みの圧電材料プレート４２を固定板４５に仮固定する。この固定板４５には、ノズルプレート２９、圧力室プレート４０及び振動板４１等のSUSプレートとの接合位置決めを行うためのアライメントマーカ（図示せず）が設けられている。

【０１２６】更に、図１５（ｃ）に示すように、仮固定した圧電材料プレート４２上に、感光性を有するフィルムマスク４６を貼りつける。本実施形態例では、フィルムマスク４６として、厚さ１０μmのウレタン系フィルムマスクを使用している。この後、圧電アクチュエータ

１６として残す部分のみに紫外線（UV）を透過させるパターンに形成した露光マスク４７を別途準備する。このフィルムマスク４６は、固定板４５のアライメントマーカを基準にしてパターニングされている。

【０１２７】続いて、露光マスク４７を用いて、フィルムマスク４６で被覆した圧電材料プレート４２にUV露光を行い、更に、フィルムマスク４６にエッチングを行う。エッチング液には、フィルムマスク４６のUV照射された部分を除去せず、それ以外の部分を確実に除去できる特性を有するものを選択する。本実施形態例では、炭酸ナトリウム溶液を用いた。

【０１２８】以上までのプロセスで、圧電アクチュエータ１６として残したい部分のみにフィルムマスク４６を被覆し、それ以外の部分からはフィルムマスク４６を除去する。続いて、この構造に対してサンドブラスト加工を行う。このサンドブラスト加工は、フィルムマスク４６が除去されて露出した部分の圧電材料プレート４２を確実に研削除去し、フィルムマスク４６が残った部分を研削しないような条件下で行う。

【０１２９】この後、圧電材料プレート４２の表面に残存したフィルムマスク４６を除去し、洗浄する。以上の工程によって、図１５（ｄ）に示すように、両面に電極膜３１を備え、小片化された圧電アクチュエータ１６を固定板４５上に粘着発泡テープ４４で貼りつけた構造の圧電材料を得ることができる。

【０１３０】次いで、上記圧電材料を振動板４１に貼りつける工程を行う。まず、図１５（ｄ）に示す圧電材料の表面に、接着剤（図示せず）を塗布する。本実施形態例では、振動板４１を共通電極として兼用するので、塗布する接着剤には導電性を有する接着剤を用いる。これを塗布した後に、振動板４１と固定板４５とのアライメントマーカを位置決め基準として、圧電材料と振動板４１とを重ね合わせ、１平方センチメートルあたり２kgの加圧を行い、200℃の温度下で熱硬化性の接着剤を硬化させ、双方を接合する。なお、この加熱時に圧電材料と固定板４５とを仮固定するために用いた粘着発泡テープ４４は、熱で粘着力を失うので、容易に剥離される。

【０１３１】以上の工程により、振動板４１を共通電極としその上に小片化された圧電アクチュエータ１６を備え、各圧電アクチュエータ１６上に個別電極が設けられたユニットが得られる。このユニットを、別途位置決め接着・接合しておいた振動板４１以外のノズルプレート２９、インクプールプレート３８、供給路プレート３９及び圧力室プレート４０の接合品であるプレートユニットと接着・接合する。これにより、インクジェット記録ヘッドを得ることができる。

【０１３２】最後に、各圧電アクチュエータ１６に駆動電圧波形を印加するための電気接続を行う。本実施形態例では、インクジェット記録ヘッドの外周にFPCケーブル（図示せず）を貼り付け、その電極端子と各圧電アクチュエータ１６の個別電極とをワイヤボンディングで接続した。

【０１３３】次に、本実施形態例の作動について説明する。つまり、上述のように試作したインクジェット記録ヘッドに対し、図１２に示すインクプール３８ｂからインク供給路３９ｂを経由して各圧力室１４にインクを充填する。引き続き、各圧電アクチュエータ１６の個別電極と振動板４１（共通電極）との間に駆動電圧を印加すると、振動板４１と圧電アクチュエータ１６とから成る振動要素が撓み変形して、圧力室１４内に充填されたインクを圧縮することにより、対応するノズル１３からインク滴が吐出する。

【０１３４】以上のインクジェット記録ヘッドを用い、インク滴の吐出実験を行った。図１６は、この実験で用いた駆動電圧波形を示すグラフである。グラフでは、縦軸に電圧［Ｖ］を、横軸に時間［μｓ］をとっている。

【０１３５】まず、図１６に示す駆動電圧波形を各振動要素に個別に入力する。その結果、各ノズル１３から20plのインク滴が安定して吐出することを確認した。更に、同時に駆動する振動要素の数を変化させて同様の実験を行った。その結果、駆動する個数に拘わらず、同じ滴量のインク滴を安定して吐出できることを確認した。また、駆動する場所による吐出特性（吐出滴体積、吐出滴速度、吐出方向）の差異も確認されなかった。

【０１３６】本実施形態例のインクジェット記録ヘッドでは、振動要素の音響容量ｃ０は、有限要素法による構造解析及び実測評価により３．２×１０$^{-20}$ｍ^5／Ｎと求められた。すなわち、本実施形態例のインクジェット記録ヘッドは、

$$c_0 \geqq 2.0\times10^{-20}\ [\mathrm{m^5/N}]$$

の条件を満たしている。

【０１３７】つまり、$c_0 \geqq 2.0\times10^{-20}\mathrm{m^5/N}$の条件を満たせば、15pl以上の大滴吐出が可能となることが、本実施形態例の実験結果よって確認された。

【０１３８】第２実施形態例

図１７は、本実施形態例のインクジェット記録ヘッドを展開した斜視図である。このインクジェット記録ヘッドでは、インク流路は、ノズルプレート１、共通流路プレート２、供給路プレート４、圧力室プレート５、及び振動板６の合計５枚のプレートを接着剤によって積層接合することにより形成されている。

【０１３９】共通流路は、１本の主流路７と２６本（図１７では５本のみ表示）の分岐流路８とによって構成されている。主流路７は、供給口９を介してインクタンク（図示せず）に連通しており、各分岐流路にインクを供給する機能を有する。各分岐流路８には夫々、１０個ずつの圧力室１４が連結されている（図１７では５個のみ表示）。つまり、本実施形態例のインクジェット記録ヘッドは、２６０個のイジェクタを有するマトリクス状配列ヘッドとして構成されている。

【０１４０】図１８はイジェクタ１個の断面を示した図である。圧力室１２は、インク供給孔１１を介して分岐流路８に連結されており、圧力室１２内にインクが充填される。各圧力室１２には、インク滴を吐出するためのノズル１０が連結されている。また、圧力室１２の底面には振動板６が設けられており、振動板６には圧電アクチュエータ２７が取り付けられている。この圧電アクチュエータ２７に駆動電圧波形を印加すると、圧電アクチュエータ２７が撓み変形し、圧力室１２を膨張又は圧縮させる。圧力室１２に体積変化が生じると、圧力室１２内に圧力波が発生する。この圧力波の作用によってノズル部のインクが運動し、ノズル１０から外部へ排出されてインク滴が形成される。なお、２４は連通路を示す。

【０１４１】本実施形態例では、ノズルプレート１に厚さ２５μmのポリイミドフィルムを用い、エキシマレーザ加工によって、開口径２５μmのノズル１０を形成した。本実施形態例のように、ノズルを形成する部材（ノズルプレート１）に樹脂フィルムを用いると、ノズルプレート１を分岐流路８のエアダンパとして機能させることができ、多ノズル同時吐出時の吐出安定性を向上させることができる。すなわち、図１８に示したようなヘッド構造において、ノズル１０が形成されるノズルプレートを樹脂フィルムで形成すると、分岐流路８の壁面の一部（上面）も樹脂フィルムとなる。分岐流路の壁面を剛性の低い樹脂フィルムで構成すると、分岐流路の音響容量が大幅に増加し、分岐流路を介した音響波の伝播（クロストーク）等の発生を防止することができ、多ノズル同時吐出時の吐出安定性を向上させることができる。なお、分岐流路に十分な音響容量を確保し、且つノズル部にノズルとしての機能（吐出方向性向上、気泡巻き込み防止など）を付与するためには、樹脂フィルムの厚さは２０～７０μmの範囲内であることが好適である。但し、この好適範囲以外であっても、同様の作用効果を不十分ながら得ることは可能である。供給路プレート４には、厚さ７５μmのステンレス板を用い、プレスによって開口径２６μmのインク供給孔１１を形成した。

【０１４２】共通流路プレート２及び圧力室プレート５には、厚さ１００μmのステンレス板を用い、ウェットエッチングによって流路パターンを形成した。圧力室１２は、一辺の長さが５００μm、アスペクト比１の四角形とし、圧力室１２の角部には、図１９（ａ）に示すように、インク流れの淀みを防止するためにＲ形状を付与した。振動板６には、厚さ１０μmのステンレス板（Ｅv＝１９７ＧＰａ）を用いた。図１９（ａ）におけるＰｘは主走査方向４２８（図４２参照）のノズルピッチ、Ｐｙは副走査方向４２９のノズルピッチを夫々示している。

【０１４３】図１９（ｂ）は、本実施形態例で用いた圧電アクチュエータ２７の形状を示した図である。圧電アクチュエータ２７には厚さ３０μmの単板状圧電セラミクス（チタン酸ジルコン酸鉛系セラミクス）（Ｅｐ＝２００ＧＰａ）を用いた。圧電アクチュエータの幅Ｗｐは圧力室幅Ｗとほぼ等しい４９０μmとし、加工にはサンドブラスト加工法を用いた。なお、３７は電極パッド部、３８は駆動部を夫々示す。

【０１４４】有限要素法による構造解析及び実測評価の結果、本実施形態例のインクジェット記録ヘッドでは、振動要素の音響容量c_0は$3.2\times10^{-20}\mathrm{m^5/N}$、イナータンス$m_0$は$1.3\times10^{6}\mathrm{kg/m^4}$と求められた。また、圧力室１２の音響容量は$2.0\times10^{-20}\mathrm{m^5/N}$であった（$c_c=1.2\times10^{-20}\mathrm{m^5/N}$）。つまり、本実施形態例のインクジェット記録ヘッドは、式（８）及び式（１０）の条件を満たしている。

【０１４５】図４０に、本実施形態例で使用した駆動電圧波形を示す。図４０（ｃ）に示す大滴用駆動電圧波形は、比較的緩やかな立ち上げ時間で圧力室を圧縮するための第１電圧変化プロセス４０２”、及び、一定期間電圧を保持した後に印加電圧を基準電圧（オフセット電圧V_b）に戻すための第２電圧変化プロセス４０４”によって構成されている。この駆動電圧波形が圧電アクチュエータに印加されると、第１電圧変化プロセス４０２”が印加されたタイミングで圧力室内に大きな圧力が発生し、ノズル内のインクが記録紙に向けて噴射される。区間t_3”＝５μｓ、区間t_4”＝１０μｓ、区間t_7”＝１５μｓ、電圧変化量V_2”＝３０Ｖ、バイアス電圧V_b＝２０Ｖに夫々設定した。

【０１４６】一方、図４０（ａ）に示す小滴用駆動電圧波形は、吐出直前に圧力室を膨張させるための第１電圧変化プロセス４０１、圧力室を急激な速度で圧縮するための第２電圧変化プロセス４０２、圧力室を急激な速度で膨張させるための第３電圧変化プロセス４０３、及び印加電圧を基準電圧に戻すための第４電圧変化プロセス４０４によって構成されている。この駆動電圧波形が圧電アクチュエータに印加されると、第１電圧変化プロセス４０１によってノズル開口部のメニスカスが一旦圧力発生室側に引き込まれ、凹形状のメニスカスを形成する。

【０１４７】その後、第２電圧変化プロセス４０２が加えられると、ノズル中央部に細い液柱が形成され、更に第３電圧変化プロセス４０３によって液柱が早期に分断されることにより、ノズル径よりも小さなインク滴が吐出される。すなわち、本駆動電圧波形はメニスカス制御方式によって微小滴を吐出するための駆動波形である。区間t_1＝２μｓ、区間t_2＝２μｓ、区間t_3＝２μｓ、区間t_4＝０．５μｓ、区間t_5＝２μｓ、区間t_6＝５μｓ、区間t_7＝１５μｓ、電圧変化量V_1＝１５Ｖ、電圧変化量V_2＝１２Ｖ、電圧変化量V_3＝１７Ｖ、バイアス電圧V_b＝２０Ｖに夫々設定した。

【０１４８】図４０（ｂ）に示す中滴用駆動電圧波形は、小滴と同様にメニスカス制御を利用したもので、吐

出直前に圧力室を膨張させるための第１電圧変化プロセス４０１’、圧力室を急激な速度で圧縮するための第２電圧変化プロセス４０２’、及び印加電圧を基準電圧に戻すための第３電圧変化プロセス４０４’によって構成されている。小滴用駆動電圧波形の第３電圧変化プロセス４０３のように液柱の早期分断を行わず、第２電圧変化プロセス４０２’の後に一定期間電圧を保持するため、小滴よりも若干大きなインク滴が吐出される。区間t_1’＝２μｓ、区間t_2’＝２μｓ、区間t_3’＝２μｓ、区間t_4’＝１０μｓ、区間t_7＝１５μｓ、電圧変化量V_1’＝１５Ｖ、電圧変化量V_2’＝２０Ｖ、バイアス電圧V_b＝２０Ｖに夫々設定した。

【０１４９】なお、図４０に示した駆動波形は、本発明のインクジェット記録ヘッドの駆動方法を示す一例であり、その他の形状の駆動波形を用いることも可能である。すなわち、大滴吐出用の波形としては、圧力室の体積を収縮させる方向に電圧を印加してインク滴を吐出させる第1電圧変化プロセスと、前記圧力室の体積を膨張させる方向に電圧を印加する第２電圧変化プロセスとを少なくとも含めば、図４０（ｃ）と異なる形状の駆動波形を用いてもかまわない。

【０１５０】例えば、第１電圧変化プロセス４０２”の直前に、メニスカスをノズル内部に僅かに引き込むための電圧変化プロセスを加えたり、第２電圧変化プロセス４０４”の後に別の電圧変化プロセスを加えてもかまわない。同様に、小滴吐出用の波形としては、前記圧力室の体積を膨張させる方向に電圧を印加する第1電圧変化プロセスと、前記圧力室の体積を圧縮する方向に電圧を印加する第２電圧変化プロセスとを少なくとも含めば、図４０（ａ）と異なる形状の駆動波形を用いてもかまわない。例えば、第３電圧変化プロセス４０３及び第４電圧変化プロセス４０４を有しない駆動波形としたり、第１電圧変化プロセス４０１の直前に、メニスカスの初期状態を制御するための別の電圧変化プロセスを加えたりしてもかまわない。

【０１５１】図４１は、本実施形態例で用いた駆動回路の基本構成を示した図である。滴径変調方式による画像記録を実行する際には、各圧力室に対応した圧電アクチュエータに、図４０に示した駆動電圧波形を各圧力室毎に切り替えながら印加し、吐出させるインク滴の滴径を変化させる。本実施形態例では、図４０（ａ）～（ｃ）に示した３種の駆動電圧波形を発生させるために３種類の波形発生回路４１１、４１１’、４１１”を備えており、各波形は増幅回路４１２、４１２’、４１２”によって増幅される。記録時には、画像データに基づいて、圧電アクチュエータ４１４、４１４’、４１４”に印加される駆動電圧波形がスイッチング回路４１３、４１３’、４１３”によって切り替えられ、所望滴径のインク滴が吐出される。

【０１５２】以上述べた本実施形態例のインクジェット記録ヘッドを用いてインク滴の吐出実験を行った。図４０（ｃ）に示した駆動波形（V_1”＝３０Ｖ）を圧電アクチュエータ２７に印加した結果、各ノズル１０から滴体積２０ｐｌのインク滴が安定して吐出されることが確認された。すなわち、音響容量$c_0 \geqq 2.0\times10^{-20}m^5/N$の条件を満たす圧電アクチュエータ２７を用いることによって、１５ｐｌを超える大滴の吐出が可能となることが実験的に確認できた。また、リフィル時間も約４０μｓと短かく、１８ｋＨｚの高速駆動が可能であった。

【０１５３】本実施形態例のインクジェット記録ヘッドを用いて記録紙上に画像記録を行った結果、６００ｄｐｉの低い記録解像度でも、十分な画像濃度（ＯＤ値１．３）を得ることができた。すなわち、本実施形態例のインクジェット記録ヘッドでは、滴体積２０ｐｌの大滴吐出が可能であることから、６００ｄｐｉという低い記録解像度でも十分な画像濃度を得ることができ、高速記録に極めて有利なインクジェット記録ヘッドであると言える。なお、駆動波形の印加電圧をV_1”＝４０Ｖに増加させた場合には、２７ｐｌの滴体積が得られ、３００ｄｐｉの記録解像度でも十分な画像濃度（ＯＤ値１．２）を得ることができた。

【０１５４】図２１は、本実施形態例のインクジェット記録ヘッドのメニスカス振動をレーザードップラー計によって観測した結果である。圧力波の固有周期T_cは９．５μｓと小さく抑えられていることが確認された。すなわち、音響容量$c_0 \leqq 5.5\times10^{-19}m^5/N$の条件を満たす振動要素を用いることによって、微小滴吐出に適した１５μｓ以下の固有周期Ｔｃを得ることができた。

【０１５５】また、図２１のメニスカス振動波形から判るように、本実施形態例のインクジェット記録ヘッドでは、メニスカス振動に細かい振動が重畳せず、極めて良好なメニスカス振動を得ることができた。これは、本実施形態例のインクジェット記録ヘッドが、式（８）及び$c_0 > c_1$の条件を満たしており、前述した振動系Ｂの振幅を小さく抑えられているためである。メニスカスにこのような安定した振動が得られているため、本実施形態例のインクジェット記録ヘッドでは極めて高い吐出安定性を得ることができた。

【０１５６】また、図４０（ａ）に示す駆動波形で小滴吐出を行ったところ、滴体積２ｐｌの微小インク滴を安定に吐出できることが確認された。すなわち、本実施形態例のインクジェット記録ヘッドでは、固有周期が９．５μｓと短く、また、メニスカスの異常振動が抑制されているため、メニスカス制御方式による微小滴吐出を良好に実行することができた。つまり、本実施形態例のインクジェット記録ヘッドでは「大滴吐出」と「小滴吐出」との両立が可能であり、図４０に示した駆動電圧波形を画像パターンに応じて切り替えながら各圧電アクチュエータに印加することにより、２～２０ｐｌの広い滴

径範囲で滴径変調記録を実行することができた。

【０１５７】比較例として、圧電アクチュエータの厚さt_p、振動板の厚さｔｖ、及び圧力室幅Ｗを変化させて、同様の特性評価を実施した。その結果、滴体積については図６の○プロットで示したように、構造解析結果と良好に一致する結果が得られた。つまり、$c_0 \geqq 2.0\times10^{-20}\,m^5/N$の範囲では１５ｐｌ以上の滴体積が得られたが、$c_0 < 2.0\times10^{-20}\,m^5/N$の条件では１５ｐｌ未満の滴体積しか得られず、十分な画像濃度を得ることができなかった。なお、$c_0 < 2.0\times10^{-20}\,m^5/N$となる条件は、Ｗ＝５００μｍ、$t_v$＝１０μｍ、$t_p$＝４５μｍや、Ｗ＝４００μｍ、$t_v$＝５μｍ、$t_p$＝３５μｍなどの組み合わせである。

【０１５８】また、$c_0>5.5\times10^{-19}m^5/N$となった場合には、１５ｐｌ以上の滴体積は得られたが、固有周期T_cが１５μｓ以上となり、４ｐｌ以下の小滴吐出を実行できなくなった。$c_0>5.5\times10^{-19}m^5/N$となる条件は、Ｗ＝７００μｍ、$t_v$＝１０μｍ、$t_p$＝１５μｍや、Ｗ＝１０００μｍ、$t_v$＝１０μｍ、$t_p$＝３５μｍなどの組み合わせである。

【０１５９】以上の結果から、１５ｐｌ以上の滴体積を確保し、かつ１５μｓ以下の固有周期T_cを得るための条件として、式（１０）が妥当であることが実験的に確認できた。なお、アスペクト比が略１の圧力室を用いた場合、振動要素の音響容量を$2.0\times10^{-20}\leqq c_0\leqq 5.5\times10^{-19}\,m^5/N$の範囲に設定するためには、圧力室幅を３００～７００μｍ（平面積０．０９～０．５mm^2）、振動板及び圧電アクチュエータの厚みを夫々、５～２０μｍ及び１５～４０μｍの範囲に設定することが望ましい。

【０１６０】また、アスペクト比が略１でない長方形の圧力室についてもヘッドの試作評価を行った。その結果、長方形の圧力室においても、式（１０）の条件を満たせば、１５ｐｌ以上の滴体積及び１５μｓ以下の固有周期を確保できることが確認できた。ただし、同じ滴体積を得るのに、２～５倍の駆動面積（圧力室の底面積）が必要となった。

【０１６１】例えば、本実施形態例のインクジェット記録ヘッドと同じ滴体積（２０ｐｌ）を得るためには、アスペクト比５のインクジェット記録ヘッドでは圧力室サイズを３００×１５００μm^2とする必要があった。これは、本実施形態例のインクジェット記録ヘッドと比較すると約２倍の圧力室面積であり、従って、ノズルの配列密度が１／２に低下したことになる。つまり、長方形形状の圧力室でも、式（１０）の条件を満たせば目標とする特性は得られるが、高いノズル密度と両立させるためには、圧力室のアスペクト比を略１に設定することが最適であることが確かめられた。

【０１６２】なお、前述したように、本実施形態例のインクジェット記録ヘッドでは、振動要素の平面形状を略正三角形、略正方形又は略正六角形とすることができるが、これら振動要素は、相互に隣接する各２辺の接合部分が曲線状に形成されることが望ましい。つまり、図１９（ａ）に示すように、圧力室１２の角部（隅）にＲ形状を付与することができる。これは、圧力室内においてインクの淀み点が発生することを防止し、気泡の排出性を向上させるためである。

【０１６３】すなわち、インクジェット記録ヘッドでは、圧力室内に発生させた圧力波によってインク滴の吐出を行うが、圧力室内に気泡が残存していると圧力発生効率が低下し、インク滴の体積や滴速が減少してしまう。残存気泡が大きいと、滴吐出が不可能になる場合もある。そこで、通常のインクジェット記録装置では、ノズルからインクを吸引することによって圧力室内の気泡除去を行っている。しかし、圧力室のアスペクト比が１に近く、且つ圧力室に角が存在する場合には、圧力室内にインクの淀み点（流速が遅い部分）が発生するため、気泡排出が困難になる。

【０１６４】そこで、本実施形態例のインクジェット記録ヘッドでは、圧力室の角部にＲ形状を付与することにより、淀み点の発生を防止し、気泡排出性を向上させた。実際、一定の条件（ノズルから２００ｍｍＨｇの圧力で５秒間インクを吸引）でインク吸引を行った後における圧力室内の気泡残存率を調べた結果、Ｒ形状（曲線形状）を付加した本実施形態例のインクジェット記録ヘッドでは気泡残存率が０であったのに対し、Ｒ形状を付与しない場合には１５％の圧力室で気泡残存が確認された。

【０１６５】本実施形態例のインクジェット記録ヘッドでは、多数の圧力室及び圧電アクチュエータがマトリクス状に高密度配列されているため、夫々の圧電アクチュエータに電気接続を行うことが極めて困難となる。すなわち、図３５に示すように、圧力室が１次元的に配列されている場合や、第１実施形態例のように２次元配列でも圧力室の数が少ない場合には、従来の電気接続方法（ワイヤボンディング等）によって容易に電気接続を行うことが可能であるが、本実施形態例のように多数の圧力室を２次元的に高密度配列した場合には、従来の電気接続方法を適用することは不可能である。

【０１６６】そこで、本実施形態例では、図２２及び図２３に示すような電気接続方法を用いた。すなわち、圧電アクチュエータに電極パッド部３７（図１９（ｂ）参照）を設け、図２２に示すように、この電極パッド部と配線基板（ＦＰＣ基板）３１１とを半田バンプを介して電気接続することにより、各圧電アクチュエータに電圧を印加した。以下、本実施形態例の電気接続方法について更に詳しく説明する。

【０１６７】図２２（ａ）及び（ｂ）は夫々電気接合前／後の斜視図、図２３（ａ）及び（ｂ）は夫々、図２２（ａ）のＡ－Ａ線に沿った断面図、及び図２２（ｂ）のＢ－Ｂ線に沿った断面図である。マトリクス状に配列さ

れた圧電アクチュエータ３１２の対向する２面には、共通信号用電極３２１と個別信号用電極３２２とが夫々形成されており、共通信号用電極３２１は、導電性の振動板３１３と電気的及び機械的に接合されている。共通信号用電極３２１はＣｒ（０．２μｍ）とＡｕ（０．２μｍ）との二層構造、個別信号用電極３２２はＣｒ（０．２μｍ）とＮｉ（０．６μｍ）とＡｕ（０．２μｍ）との三層構造とした。

【０１６８】個別信号線（信号ライン）が形成されたフレキシブルプリント配線基板（ＦＰＣ基板）３１１は、樹脂材からなるベースフィルム３２３、金属導体からなる配線パターン３２４、カバーレイヤ３２５の三層から構成されている。また、圧電アクチュエータの電極パッド部３２６と対応する位置には個別信号用電極３２７が形成されており、この電極３２７上には、導電性のコア材３２８及び導電性の接合材３２９で構成される半球状のバンプ３３０が形成されている。本実施形態例では、コア材３２８としてＣｕを用い、コア材３２８の表面に、電解メッキ法により接合材としてハンダを形成してバンプを作製した。本実施形態例では、バンプの径をφ１５０μｍ、高さを６０μｍに設定した。

【０１６９】電気接合時には、ＦＰＣ基板３１１と圧電アクチュエータ３１２を相互に対向させ、電極パッド部とバンプとの位置が一致するようにアライメントを取った状態で加圧・加熱を行い、接合材を電極パッド上で溶融・流動させることにより、電極パッドとバンプ３３０を電気的及び機械的に接合する。振動板３１３及びＦＰＣ基板３１１上の電気接合用パッド３２７は制御回路（図示せず）と電気的に接合されており、個別信号線を介して圧電アクチュエータ３１２に駆動電圧が印加される。

【０１７０】本実施形態例のインクジェット記録ヘッドでは、バンプ３３０を半球状に形成している。これは、電極パッド部とバンプとのコンタクト状態を確実に且つ均一にするためである。すなわち、ＦＰＣ基板３１１と圧電アクチュエータ３１２との平行度にズレが生じた場合でも、バンプを半球状としておくことで、電極パッド部とバンプ３３０との接触状態を均一化することができ、安定した電気接続が可能になると同時に、電気接続時における圧電アクチュエータ３１２の破壊を防止することができる。

【０１７１】また、本実施形態例のインクジェット記録ヘッドでは、配線基板に柔軟性の高いＦＰＣ基板３１１を用いているが、これも、電極パッド部とバンプ３３０との間で確実なコンタクトを確保するためである。つまり、配線基板を柔軟性の低い剛体材料で構成すると、圧電アクチュエータが接合された流路板の反りや圧電アクチュエータの厚さのバラツキによって、部分的に電極パッド部とバンプ３３０との間にコンタクト不良が発生し易い。一方、配線基板を柔軟性の高い材料で構成すると、配線基板の変形によって上記の反りや厚さばらつきを吸収することができ、全ての電気接続部分で均一なコンタクトを確保することができる。

【０１７２】また、配線基板に柔軟性の高い材料を用いると、圧電アクチュエータ３１２を駆動した際に、バンプ３３０と配線基板３１１との間に発生する応力を低減することができる。すなわち、圧電アクチュエータ３１２を駆動すると、電極パッド部も多少変位するため、電極パッド部上のバンプ３３０も一緒に変位する。このとき、配線基板に剛性の高い基板を用いていると、電極パッド部、バンプ、及び配線基板の夫々の間で大きな応力が発生し、電気接続部の破断を生じさせるなど、電気接続部の信頼性を大きく低下させる原因となる。これに対し、本実施形態例のように配線基板に柔軟性の高い材料を用いれば、バンプの変位に応じて配線基板が変形できるため、応力の発生を抑制することができ、信頼性の高いインクジェット記録ヘッドを実現することが可能となる。

【０１７３】更に、本実施形態例のインクジェット記録ヘッドでは、バンプ４４０の内部にコア材３２８を挿入している。これにより、電気接続後において圧電アクチュエータ３１２とＦＰＣ基板３１１との間に間隙を形成することが可能になるので、圧電アクチュエータ３１２がＦＰＣ基板に拘束されることなく自由に撓み変形することが可能となる。つまり、圧電アクチュエータ３１２と配線基板３１１との接触に起因する圧電アクチュエータ３１２の特性不良を防止することができ、信頼性の高いインクジェット記録ヘッドを実現することが可能となる。また、圧電アクチュエータ３１２とＦＰＣ基板３１１との間に間隙が存在すると、圧電アクチュエータ３１２の駆動によって発生した熱を自然空冷又は強制空冷することが可能となり、温度上昇による圧電アクチュエータ特性の変化を抑制することも可能となる。

【０１７４】上記のような電気接続方法を用いることにより、２次元的に高密度配列された圧電アクチュエータ３１２に対しても確実な電気接続を可能とすることができる。すなわち、配線基板３１１は圧電アクチュエータ３１２の上方に配置されるため、信号線を配置するスペースを最大限に確保することができ、結果的にノズルの配列密度を高く設定することが可能となる。

【０１７５】例えば、サイズが５００×５００μm^2の圧電アクチュエータ３１２を１０×１０でマトリクス状に配列する場合、ＦＰＣ基板３１１上に５０μｍピッチの配線パターンを形成することは容易であるため、５７５μｍピッチまで圧電アクチュエータ３１２の配列ピッチを小さく設定することができる。これは、図２４（ａ）及び（ｂ）に示すようなマトリクス状配列ヘッドにおける従来の電気接続方法では実現できない数値である。

【０１７６】例えば、図２４（ｂ）に示すように、圧電

アクチュエータ３３１と同一平面に個別信号線３３５を形成するような従来の電気接続技術では、スクリーン印刷による最小配線ピッチが一般的に０．３ｍｍ程度であるため、圧電アクチュエータ３３１の配列ピッチは約３．６ｍｍが下限となる。つまり、本実施形態例のような電気接続方法は、マトリクス状配列ヘッドにおけるノズル密度を向上させる上で極めて有効な方法と言える。図中の３３３、３３６は夫々、配線基板を示している。

【０１７７】第３実施形態例

図２５（ａ）は、本実施形態例のヘッド構造を示す平面図である。本実施形態例のインクジェット記録ヘッドは、基本構造は第１実施形態例とほぼ同じであるが、圧電アクチュエータ２４１の幅W_pを圧力室２４２の幅Wよりも小さく設定している点に特徴を有する。すなわ＊ち、圧電アクチュエータ２４１の幅W_pを圧力室幅Wよりも小さく設定することにより、圧電アクチュエータを振動板上に接合する際に位置ずれが発生しても、振動要素の音響容量c_0が大きく変動するのを防ぐことができ、滴体積及び固有周期の変化を最小に抑えることが可能となる。

【０１７８】図２６は、圧力室２４２と圧電アクチュエータ２４１の駆動部２４３（実際に撓み変形する部分）の中心位置ずれをδ［μｍ］としたときに、圧電アクチュエータ２４１の幅W_pによって音響容量c_0にどれだけの変化が発生するかを調べた結果である。この結果より、W_pを以下の条件（式(11)）を満足するように設定すれば、滴体積の変化を小さく抑制できることが明らかになった。

$$W_p \leqq (W-2\delta) \quad \text{又は} \quad W_p \geqq (W+2\delta) \qquad (11)$$

【０１７９】上記の条件下で圧電アクチュエータの位置ずれに対するロバスト性（鈍感さ）が向上する理由は、圧電アクチュエータ端部の支持条件が常に一定となるためである。すなわち、図２５（ａ）のように、$W_p \leqq (W-2\delta)$の条件を満たすように圧電アクチュエータ幅を圧力室幅よりも小さく設定すれば、±δの位置ずれが発生しても圧電アクチュエータの駆動部２４３が圧力室２４２の隔壁上に重なることはない。そのため、駆動部２４３の端部は常に回転支持条件として保たれるため、位置ずれが発生しても圧電アクチュエータの変形のしやすさが大きく変化することがなく、音響容量c_0はほぼ一定の値となる。

【０１８０】一方、図２５（ｂ）のように、$W_p \geqq (W+2\delta)$の条件を満たすように圧電アクチュエータ幅を圧力室幅よりも大きく設定すれば、位置ずれが発生しても駆動部２４３が圧力室２４２の隔壁上に常に重なっているため、駆動部端部は常に固定支持条件として保たれ、位置ずれが発生しても音響容量c_0が大きく変化することはない。※【０１８１】以上のように、位置ずれが発生しても駆動部端部の支持条件が一定に保たれるように、圧電アクチュエータ２４１の幅W_pを式（１１）の条件を満足するように設定すれば、位置ずれによる音響容量c_0の変動を最小限に抑えることができ、位置ずれに対するロバスト性を向上させることが可能となる。

【０１８２】ただし、$W_p \geqq (W+2\delta)$として駆動部端部を固定支持条件とすると、圧電アクチュエータの変形が端部によって拘束されるため、回転支持条件の場合と比較するとc_0が大幅に減少する。また、$W_p \leqq (W-2\delta)$の場合にも、W_pが小さすぎると吐出効率が低下してしまう（実質的な駆動面積が低下してしまうため）。

【０１８３】図２７は、吐出効率とバラツキとの関係を調べた結果である（δ＝２０μｍ）。この結果から、位置ずれに対するロバスト性を確保し、且つ高い吐出効率を得るためには、以下の条件式を満足する必要があることが判った。

※

$$0.9(W-2\delta) \leqq W_p \leqq (W-2\delta) \qquad (12)$$

【０１８４】本実施形態例では、圧電アクチュエータの接合時に発生する最大位置ずれ量δが２０μｍであったため、W_pを４６０μｍに設定した（圧力室幅Wは５００μｍ）。すなわち、±２０μｍの位置ずれが発生しても、吐出効率に大きな影響が発生しないように設定した。

【０１８５】実際に複数の記録ヘッドを作製して吐出効率（インク滴体積）のばらつきを調べた結果、δ＝２０μｍの位置ずれが発生したヘッド間においても、吐出効率の差が５％以下に収まることが確認された。また、位置ずれを故意に３０μｍ以上に増加させて評価を行ったところ、吐出効率に１０％以上の差が発生することが確認された。つまり、式（１２）の条件を満足することによって、位置ずれに対するロバスト性を向上できることが確認できた。

【０１８６】なお、圧電アクチュエータの位置ずれ量δは、圧電アクチュエータの接合時のアライメント方法に依存するが、アライメントマークを基準とした一般的なアライメント方法を用いた場合、±１０～±３０μｍ程度となる。従って、駆動部の幅Ｗｐは、圧力室幅Wよりも±１０～±３０μｍ程度小さく設定することが最適である。

【０１８７】また、図２５（ｂ）のように、圧力室幅Wが５００μｍであるのに対し、W_pを５４０μｍに設定した圧電アクチュエータについても評価を行った。この場合には、±２０μｍの位置ずれが発生しても、駆動部の境界条件が常に固定端となるため、音響容量c_0の変動を抑制することができる。実際に、位置ずれによる滴体積の変化を調べた結果、吐出効率の差が５％以下と小さいことが確認された。ただし、駆動部の境界条件が固

定端のため、図２５（ａ）の構造に比べると吐出効率が１／５以下であり、大滴吐出には不利な構造であると言える。

【０１８８】本実施形態例のインクジェット記録ヘッドでは、振動要素の音響容量c_0は３．５×１０$^{-20}$m^5／Ｎ、イナータンスm_0は１．０×１０^{6}ｋｇ／m^{4}と求められた。つまり、本実施形態例のインクジェット記録ヘッドも式（８）及び式（１０）の条件を満足しており、その結果、滴体積１９ｐｌ（V_1＝３０Ｖ）、固有周期９．８μｓを得ることができた。

【０１８９】<u>第４実施形態例</u>

図２８は、本実施形態例のヘッド構造を示す平面図である。本実施形態例のインクジェット記録ヘッドは、基本構造は第３実施形態例とほぼ同様であるが、圧電アクチュエータの形状を、駆動部２７３、電極パッド部２７４、及びブリッジ部２７５から構成している点に特徴がある。

【０１９０】すなわち、圧電アクチュエータ２７１は、貫通穴２７８の形成により駆動部２７３と電極パッド部２７４とに分離され、駆動部２７３の変位の小さい部分でブリッジ部２７５を介して接続されている。これにより、圧電アクチュエータ２７１の電極パッド部２７４による変位拘束が低減されるので、吐出効率の高いインクジェット記録ヘッドを実現することができる。

【０１９１】図２８の等高線２７６で表わしたように、アスペクト比が１に近い圧力室２７２に撓み変形する圧電アクチュエータ２７１を取り付けた場合、振動要素は球面に近い形状に変形する。そのため、振動部の中心から離れた部分ほど変位量が小さくなる。圧電アクチュエータ２７１が多角形（四角形、六角形など）の場合、中心から離れた部分とは振動部２７３の角の領域となる。従って、本実施形態例のように、振動部２７３の角部にブリッジ部２７５を連結することにより、圧電アクチュエータ２７１の変位拘束を最小化しながら駆動部２７３への電圧印加（電気接続）を可能にすることができる。

【０１９２】実際に、本実施形態例のインクジェット記録ヘッドを吐出評価した結果、図２５の構造に比べ、吐出効率を２０％増加することができた。すなわち、V_1＝３０Ｖで２３ｐｌの滴体積を得ることができた。なお、本実施形態例のインクジェット記録ヘッドでは、振動要素の音響容量c_0は３．７×１０$^{-20}$m^5／Ｎ、イナータンスm_0は１．０×１０^{6}ｋｇ／m^{4}であり、本実施形態例のインクジェット記録ヘッドも式（８）及び式（１０）の条件を満足している。

【０１９３】図２９は、ブリッジ部の幅Ｗｂと吐出効率との関係を、構造解析及び実際の吐出評価によって調べた結果である。ブリッジ部の幅が小さいほど変位拘束力が小さくなり、吐出効率が増加する傾向が見て取れる。ただし、ブリッジ部の幅を過小とすると、製造時又は使用時においてブリッジ部にクラックが発生し、正常なインク滴吐出を実行できなくなる恐れがある。従って、ブリッジ部の幅Ｗｂは駆動部の幅Ｗｐに対して１／２以下、１／４以上に設定することが望ましい。

【０１９４】圧電アクチュエータ２７１の形状は、図２８のような形状に限定されるものではなく、図３０（ａ）～（ｄ）に示すように、種々の形状を適用することが可能である。つまり、ブリッジ部２７５が駆動部２７３の中心から離れた部分に連結されていれば、ブリッジ部２７５や電極パッド部２７４の形状はいかなる形状であってもよく、また、ブリッジ部２７５の個数も１本又は複数であってもよい。

【０１９５】また、本実施形態例のように、圧電アクチュエータ２７１の駆動部２７３と電極パッド部２７４とを分離することは、圧電アクチュエータ２７１の電気接続を行う上でも有利である。すなわち、図２５に示したような圧電アクチュエータ２４１の形状では、駆動部２４３と電極パッド部２４４が分離されていないため、図２２及び図２３に示したＦＰＣ基板を使用した電気接続方法を用いた際に、図２３（ａ）、（ｂ）に示す接合材３２９が駆動部領域に流入し、接合材が圧電アクチュエータの変形を拘束する恐れがある。特に、圧力室２４２を高密度配列した場合には、駆動部と電極パッド部の距離が短くなるため、そうした接合材流入の問題が発生しやすくなる。

【０１９６】一方、本実施形態例のように、駆動部と電極パッド部を分離した形状にすると、駆動部への接合材流入を有効に抑制することができるため、信頼性の高いインクジェット記録ヘッドを実現することが可能となる。

【０１９７】本実施形態例では、圧電アクチュエータ２７１の形状が、図２８及び図３０に示すような複雑な形状となる。そこで、本実施形態例では、圧電アクチュエータの加工にサンドブラスト加工を用いた。これにより、複雑な形状の圧電アクチュエータを簡易的かつ短時間で精密に加工を行い、低コストで高密度のインクジェットを製造することが可能となる。

【０１９８】本実施形態例のインクジェット記録ヘッドでは、図２８に示すように、隣り合う圧電アクチュエータ２７１の間にダミーパターン２７７を配設した。これは、サンドブラスト加工時に発生するサイドエッチングの影響を防止し、圧電アクチュエータ２７１に高い寸法均一性を確保するためのものである。

【０１９９】すなわち、圧電アクチュエータ２７１をサンドブラスト加工すると、圧電アクチュエータ２７１の厚さ方向に対する加工（エッチング）の進行と並行して、圧電アクチュエータ２７１の幅方向へも加工が進行する（以下、サイドエッチングと呼ぶ）。このサイドエッチングは、サンドブラスト加工を行う際に、ブラスト粒子が圧電プレートの側面に対しても衝突するために発生する。そして、このサイドエッチングの加工速度（加

エレート）は、圧電プレートに形成する加工溝の幅に依存している。つまり、圧電アクチュエータ２７１の脇に形成される加工溝の幅が大きいと、サイドエッチングが速い速度で進行しやすく、逆に加工溝の幅が小さいとサイドエッチングは発生し難くなる。

【０２００】このように、サイドエッチングの進行速度が加工溝幅によって変化するため、個々の圧電アクチュエータ２７１を取り囲む加工溝幅が一定でなければ、サイドエッチングの進行速度にバラツキが生じ、その結果、圧電アクチュエータ２７１のサイズが不揃いとなってしまう。圧電アクチュエータ２７１のサイズは、吐出特性に大きく影響を及ぼすため、上記のような不均一なサイドエッチングは防止する必要がある。

【０２０１】そこで、本実施形態例のインクジェット記録ヘッドでは、相互に隣接する圧電アクチュエータ２７１の間にもダミーパターン２７７を形成し、各圧電アクチュエータ２７１を取り囲む加工溝２７９の幅がほぼ一定（約８０μｍ）になるようにした。この構成により、全ての圧電アクチュエータ２７１を同じ条件で加工することができ、寸法均一性の高い圧電アクチュエータ２７１を実現することができた。具体的には、圧電アクチュエータ２７１の幅W_pの精度を±５μｍ以下に抑えることができた。ダミーパターン２７７を設けないでサンドブラスト加工した場合には、圧電アクチュエータ２７７の幅W_pには±２０μｍ以上のばらつきが発生したことと比較すると、ダミーパターン２７７を設けることの効果は非常に高いと言える。

【０２０２】また、上記と同じ理由で、図３１に示すように、複数の圧電アクチュエータ２３１が配列された領域の外周部にもダミーパターン２３２を配設した。すなわち、多数の圧電アクチュエータ２３１が配列された領域の外周部に位置した圧電アクチュエータ２３１では、サイドエッチングが著しく発生するため、圧電アクチュエータとしての寸法精度が特に得にくい。そのため、配列された圧電アクチュエータ群を取り囲むようにダミーパーン２３２を配設することにより、外周部に位置した圧電アクチュエータ２３１においても高い寸法均一性を確保することが可能となる。なお、本実施形態例のインクジェット記録ヘッドでは、外周部のダミーパターン２３２を図３１のように一体構造としたが、細分化されたダミーパターンを並べる形態としてもかまわない。

【０２０３】上記ダミーパターンを適用した結果、本実施形態例のインクジェット記録ヘッドでは、ヘッド内の２６０個のイジェクタにおいて、吐出特性（滴体積、滴速）のばらつきを±５％以下に抑えることが可能になった。また、複数の記録ヘッド間で特性比較をした結果、記録ヘッド間での特性バラツキも±６％以下に収まることが確認され、ダミーパターン２３２を用いた上記圧電アクチュエータ構造が、ヘッド特性の均一化に極めて有効であることが実証された。

【０２０４】第５実施形態例

図４２は、本発明に係るインクジェット記録装置の実施形態例を示す図である。本実施形態例のインクジェット記録装置４２０は、インクジェット記録ヘッドを搭載するキャリッジ４２１、矢印４２８で示す主走査方向にキャリッジ４２１を走査するための主走査機構４２２、及び、記録媒体としての記録用紙４２４を、矢印４２９で示す副走査方向に搬送するための副走査機構４２３を含み構成されている。

【０２０５】インクジェット記録ヘッドは、ノズルが形成された面が記録用紙４２４と対向するようにキャリッジ４２１上に搭載され、主走査方向４２８に搬送されながら記録用紙４２４に対してインク滴を吐出することにより、一定のバンド領域４２７に対して記録を行う。次いで、記録用紙４２４を副走査方向４２９に搬送し、再びキャリッジ４２１を主走査方向４２８に搬送しながら次のバンド領域を記録する。こうした動作を複数回繰り返すことにより、記録用紙４２４の全面にわたって画像記録を行うことができる。

【０２０６】実際に、本実施形態例のインクジェット記録装置を用いて画像記録を行い、記録速度及び画像品質の評価を行った。インクジェット記録ヘッドには、上記第４実施形態例で述べたヘッド構造のものを使用した。イエロー、マゼンタ、シアン、ブラックの４色に対応させて、１色あたり２６０個のイジェクタを有するマトリクス状配列ヘッドをキャリッジ４２１上に並べて配置し、記録用紙４２４上で４色のドットを重ねあわせることにより、フルカラーの画像記録を行った。

【０２０７】大滴体積１８ｐｌ、小滴体積２ｐｌ、記録解像度は６００ｄｐｉ、吐出周波数は１８ｋＨｚに設定して記録を行った結果、Ａ４サイズ（２１０mm×２９７mm）の画像を約５秒の時間で印刷することができ、極めて高い記録速度を実現できることが実証された。また、小滴体積が２ｐｌと小さいため、ハイライト部でも粒状性が低く抑えられ、画品質の極めて高い画像記録を実現することができた。

【０２０８】比較例として、ノズル数６４個／色の従来ヘッドを用いて、同様の画像出力実験を行った。吐出可能な大滴体積は１０ｐｌが上限であったため、記録解像度は１２００ｄｐｉに設定した。小滴体積は６ｐｌ、吐出周波数は１８ｋＨｚに夫々設定した。記録速度を評価した結果、Ａ４サイズ（２１０mm×２９７mm）の画像を記録するのに約８５秒の時間を要した。また、小滴体積が６ｐｌと大きいため、ハイライト部で粒状性が目立ち、画像品質は本実施形態例と比較すると低かった。

【０２０９】以上のように、本実施形態例のインクジェット記録装置では、記録ヘッドにおける振動要素の音響容量c_0が$c_0 \geqq 2.0\times10^{-20}m^5/N$に設定されているため、低解像度に有利な大滴吐出が可能であり、また、吐出効率の高い正方形型の圧力室をマトリクス状に配列している

ため、ノズル数を大きく設定できる。そのため、従来のインクジェット記録装置と比較すると、記録速度を大幅に増加することが可能となる。また、本実施形態例のインクジェット記録装置では、記録ヘッドにおける振動要素の音響容量c_0が$c_0 \leqq 5.5\times10^{-19}m^5/N$に設定されているため、メニスカス制御方式による小滴吐出を良好に実行することができ、高い画像品質を得ることができる。すなわち、本実施形態例のインクジェット記録装置では、高速記録と高画質記録を両立することが可能である。

【０２１０】なお、本実施形態例では、ヘッドをキャリッジ４２１によって搬送しながら記録を行う形態としたが、ノズルを記録媒体の全幅にわたって配置したライン型ヘッドを用い、ヘッドを固定して、記録媒体のみを搬送しながら記録を行うなど、別の装置形態に本発明を適用することも可能である。

【０２１１】以上、各実施形態例について説明したが、本発明は、上記実施形態例の構成に限定されるものではない。例えば、上記実施形態例では、共通流路や圧力室をステンレス板によって形成しているが、セラミックスやガラスなど、他の材料を用いることも可能である。また、ヘッドの基本構造、即ち、ノズル、供給路、共通流路の構造や配置などは、図１７及び図１８に示した形態に限定されるものではなく、他の形態を用いることも可能である。

【０２１２】また、上記実施形態例では、圧力室の形状をすべて四角形としたが、その他の多角形（三角形、五角形、六角形など）や略円形の形状を用いても同様の効果が得られる。上記実施形態例は、全てマトリクス状配列ヘッドを対象としたが、圧力室を１次元的に配列したヘッド構造など、他のヘッド構造に対しても本発明は同様に適用することができる。更に、上記実施形態例では、圧電アクチュエータの加工方法（製造方法）にサンドブラスト加工を用いたが、ダイシング加工や、圧電材料を印刷によって振動板上に形成する方法など、他の加工法を用いることもできる。また、振動板と圧電アクチュエータは一体構造として成型することもできる。

【０２１３】また、上記実施形態例では、記録紙上に着色インクを吐出して文字や画像などの記録を行うインクジェット記録装置を例にとったが、本明細書におけるインクジェット記録とは、記録紙上への文字や画像の記録に限定されるものではない。すなわち、記録媒体は紙に限定されるわけではなく、また、吐出する液体も着色インクに限定されるわけではない。例えば、高分子フィルムやガラス上に着色インクを吐出してディスプレイ用のカラーフィルタを作製したり、溶融状態のハンダを基板上に吐出して部品実装用のバンプを形成したりするなど、工業的に用いられる液滴噴射装置一般に対して、本発明を利用することも可能である。

【０２１４】本実施形態例で用いたような、平面形状が正方形の振動要素以外にも、平面形状に接する外接円の

径d_1と内接円の径d_2との比d_1/d_2をＡとすると、

$1 \leqq A \leqq 2$

を満たすような平面形状の振動要素を用いることができる。つまり、正方形では$A=\sqrt{2}$（≒1.4）であるが、正三角形では$A=2$、正六角形では$A=2/\sqrt{3}$（≒1.2）、及び真円では$A=1$である。これらの平面形状を有する振動要素は、その最小幅が大きく撓み易いので、その平面積をできる限り小さくしても排除体積を維持することができる。従って、ヘッドを小型・低コスト化することが可能となる。

【０２１５】なお、振動要素の平面形状、材質、厚さは、本実施形態例で試作したものに限定されることはなく、$2.0\times10^{-20} \leqq$音響容量$c_0 \leqq 5.5\times10^{-19}\ m^5/N$の条件を満たす構造であれば、その他の組み合わせであっても本発明に係る効果を得ることができる。

【０２１６】以上、本発明をその好適な実施形態例に基づいて説明したが、本発明に係るインクジェット記録ヘッド及びその製造方法、インクジェット記録装置、並びにインクジェット記録ヘッドの駆動方法は、上記実施形態例の構成にのみ限定されるものではなく、上記実施形態例の構成から種々の修正及び変更を施したインクジェット記録ヘッド及びその製造方法、インクジェット記録装置、並びにインクジェット記録ヘッドの駆動方法も、本発明の範囲に含まれる。

【０２１７】

【発明の効果】以上説明したように、本発明によると、ヘッドサイズの大型化やコストアップを回避しつつ、同一ノズルから所要サイズの「大滴」を吐出させ、且つ「ノズル密度増加」を実現して単位面積当たりのインク滴吐出効率を高めることができるインクジェット記録ヘッド、このようなインクジェット記録ヘッドを搭載したインクジェット記録装置、並びに、インクジェット記録ヘッドの製造方法及び駆動方法を得ることができる。また、同一ノズルから所要サイズの「大滴」及び「小滴」の双方を選択的に吐出させ、高速記録と高画質記録の両立を可能とするインクジェット記録ヘッドを得ることができる。更に、メニスカスの異常振動を防止し、吐出安定性の高いインクジェット記録ヘッドを実現することができる。

【図面の簡単な説明】

【図１】本発明に係る実施形態例のインクジェット記録ヘッドに用いられる振動要素の音響回路図である。

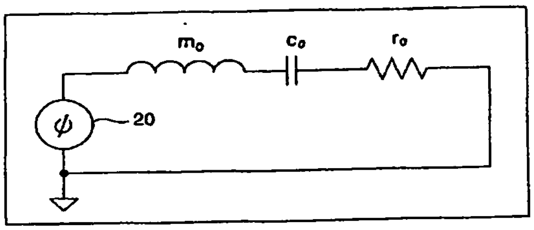
【図２】１個のイジェクタの等価電気回路を示す図である。

【図３】音響回路にステップ圧力を入力した際の排除体積と音響パラメータとの関係を示すグラフであり、（ａ）は排除体積とイナータンス、（ｂ）は排除体積と音響容量、（ｃ）は排除体積と音響抵抗との関係を夫々示す。

【図４】c_0と$\phi\cdot c_0$との関係を示す図である。

【図5】c_0とφ・c_0との関係を示す別のグラフである。
【図6】c_0とφ・c_0との関係を示す更に別のグラフである。
【図7】圧力室のアスペクト比の影響を示す図である。
【図8】アスペクト比の定義を説明するための図である。
【図9】図２（ａ）の等価回路の周波数応答を示す図である。
【図１０】１個のイジェクタの等価電気回路を示す図である。
【図１１】振動要素の音響容量c_0と圧力室の音響容量c_1の適正バランスを説明するための図である。
【図１２】本発明に係る第１実施形態例のインクジェット記録ヘッドを展開した状態で示す斜視図である。
【図１３】図１２の構成を一部透視した状態で示す平面図である。
【図１４】振動板及び圧電アクチュエータの厚さと音響容量との関係を示すグラフである。
【図１５】第１実施形態例のインクジェット記録ヘッドの製造方法を示す斜視図であり、（ａ）～（ｄ）は各工程を段階的に示す。
【図１６】インク滴の吐出実験で用いた駆動電圧波形を示すグラフである。
【図１７】本発明に係る第２実施形態例のインクジェット記録ヘッドのプレート構成を示す斜視図である。
【図１８】第２実施形態例のインクジェット記録ヘッドの断面図である。
【図１９】第２実施形態例のインクジェット記録ヘッドの平面形状を示す図である。
【図２０】大滴吐出用の駆動波形の一例を示す図である。
【図２１】本発明のインクジェット記録ヘッドのメニスカス振動を示す図である。
【図２２】本発明のインクジェット記録ヘッドの電気接続方法を示す図である。
【図２３】本発明のインクジェット記録ヘッドの電気接続方法を示す断面図である。
【図２４】マトリクス状配列ヘッドにおける従来の電気接続方法を示す図である。
【図２５】本発明に係る第３実施形態例のインクジェット記録ヘッドの圧電アクチュエータの平面形状を示す図である。
【図２６】第３実施形態例の圧電アクチュエータの位置ずれによるc_0の変化を示す図である。
【図２７】第３実施形態例の圧電アクチュエータの位置ずれによる吐出効率と滴体積ばらつきの変化を示す図である。
【図２８】本発明に係る第４実施形態例のインクジェット記録ヘッドにおける圧電アクチュエータの平面形状を示す図である。
【図２９】第４実施形態例のブリッジ幅と吐出効率の関係を示す図である。
【図３０】第４実施形態例を適用可能な圧電アクチュエータ形状の一例を示す図である。
【図３１】第４実施形態例のインクジェット記録ヘッドにおける圧電アクチュエータのブラスト加工パターンの一例を示す図である。
【図３２】メニスカス制御方式を用いた際のメニスカスの挙動を説明するための第２の模式図である。
【図３３】圧力波の固有周期と吐出可能な最小滴径の関係を示す図である。
【図３４】従来のインクジェット記録ヘッドの基本構造を示す断面図である。
【図３５】マルチノズル型インクジェット記録ヘッドの基本構造を示す図である。
【図３６】マトリクス配列型のインクジェット記録ヘッドの基本構造を示す図である。
【図３７】小滴吐出用の駆動波形の一例を示す図である。
【図３８】メニスカス制御方式を用いた際のメニスカスの挙動を説明するための模式図である。
【図３９】メニスカス振動の観測結果の一例（正常／異常）を示す図である。
【図４０】本発明に係る実施形態例で使用した駆動電圧波形を示す図である。
【図４１】本発明に係る実施形態例で使用した駆動回路の構成を示す図である。
【図４２】本発明に係るインクジェット記録装置の一実施形態例を示す図である。
【符号の説明】
１３：ノズル
１４：圧力室
１６：圧電アクチュエータ
２９：ノズルプレート
３８：インクプールプレート
３８ａ：連通孔
３８ｂ：インクプール
３９：インク供給プレート
３９ａ：連通孔
３９ｂ：インク供給路
４０：圧力室プレート
４１：振動板
４２：圧電材料プレート
４３：電極膜
４４：粘着発泡テープ
４５：固定板
４６：フィルムマスク
４７：露光マスク

【図１】



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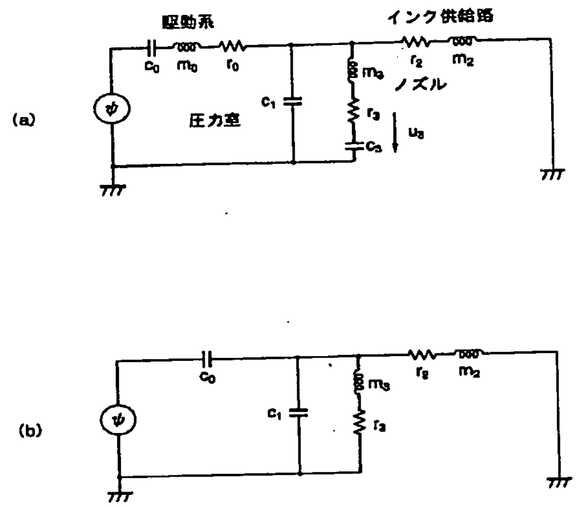

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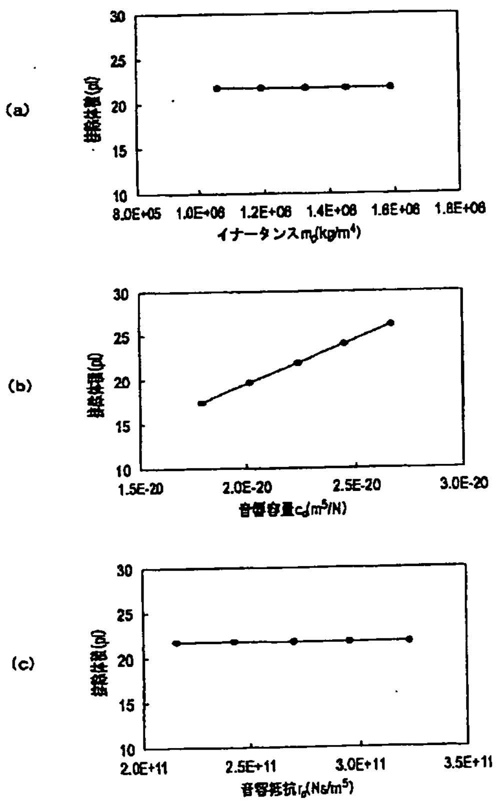

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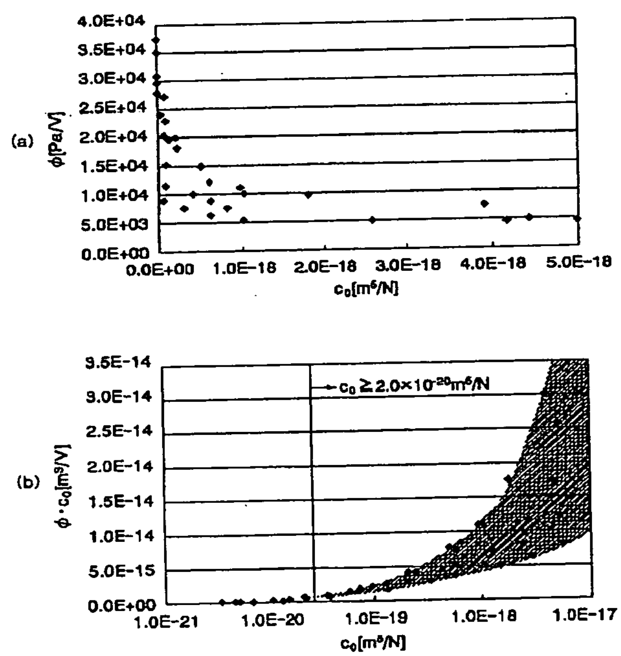

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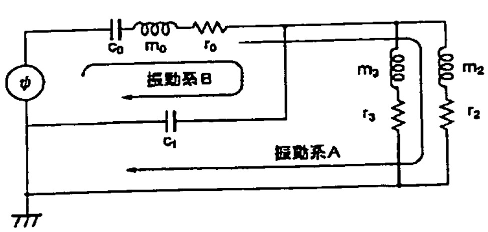

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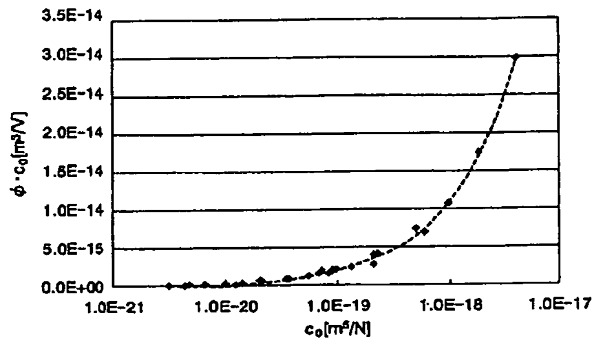

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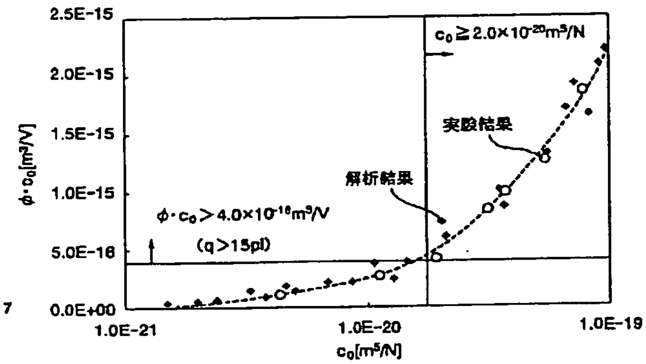

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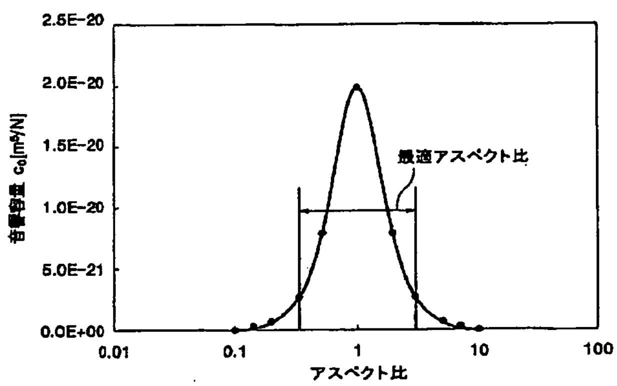

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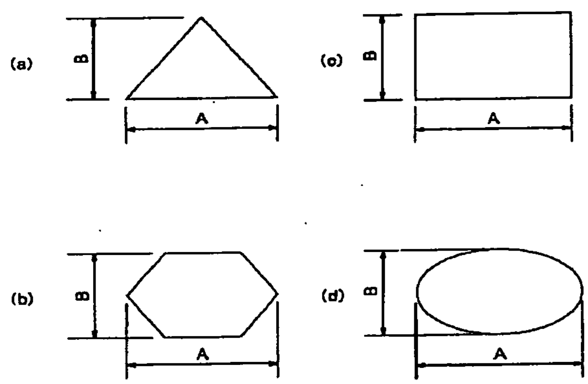

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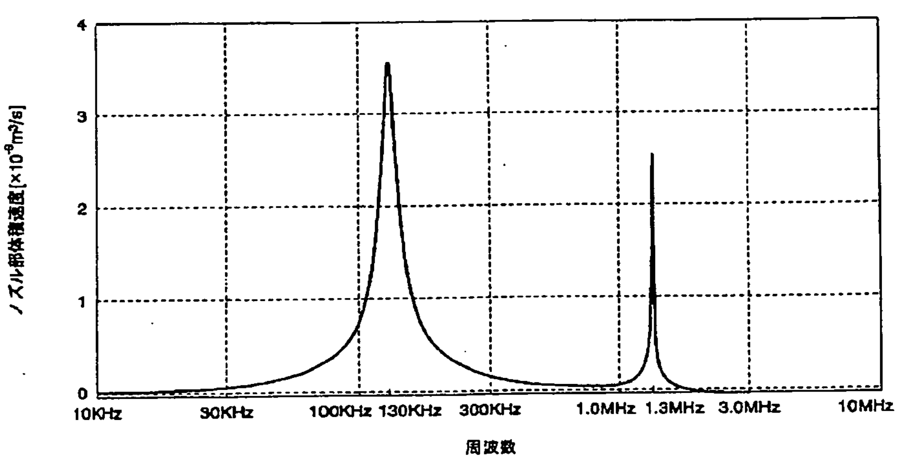

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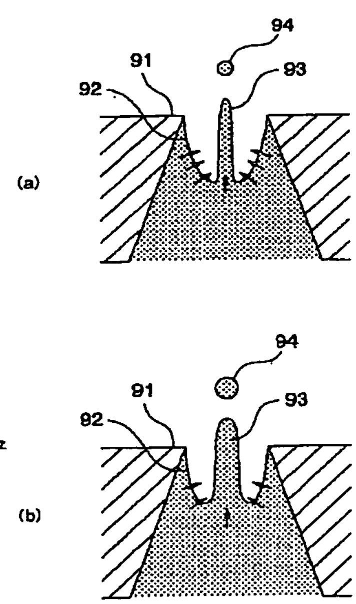

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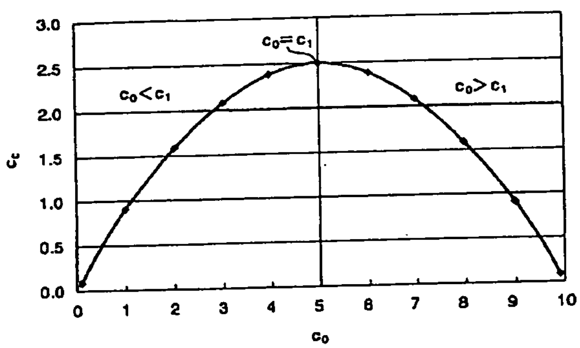

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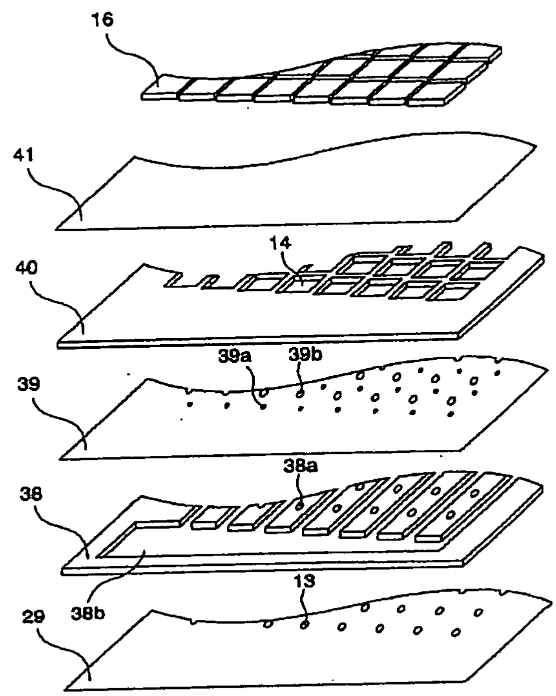

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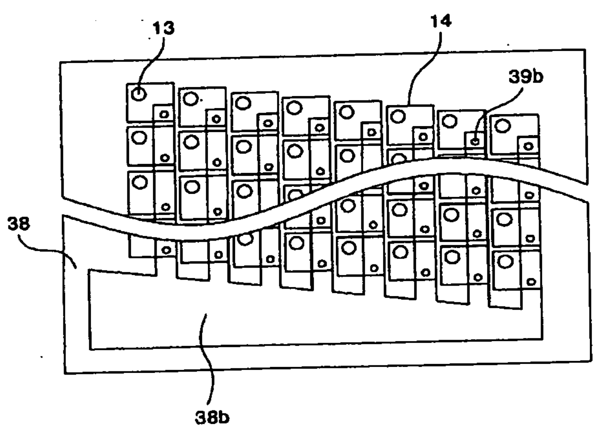

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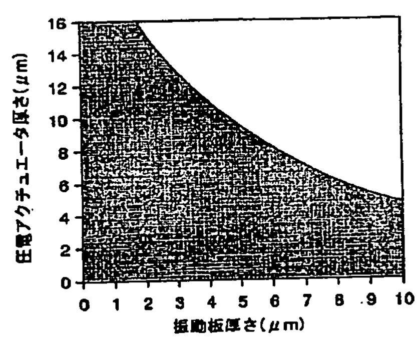

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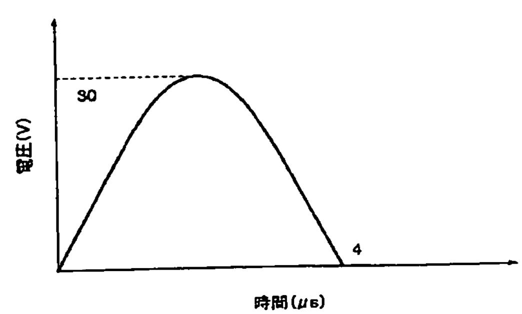

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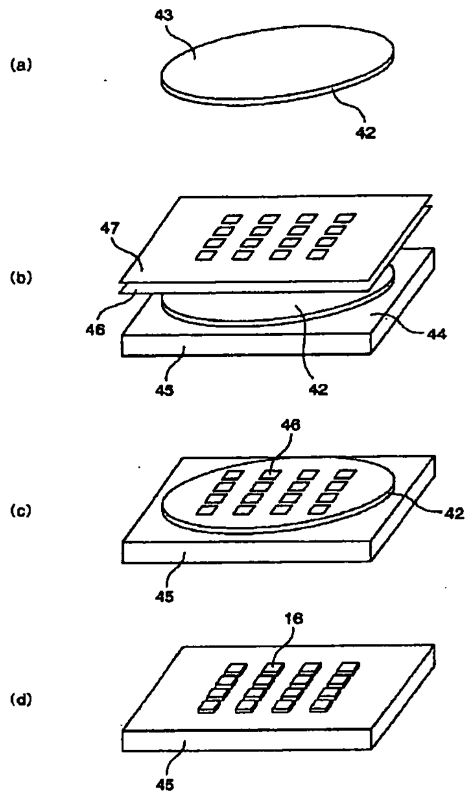

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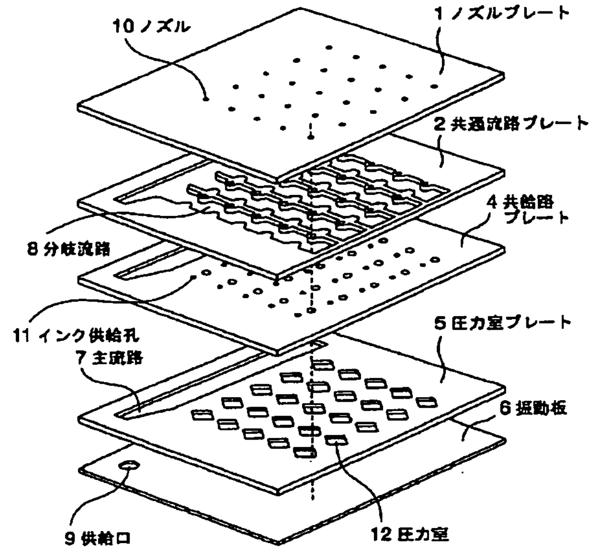

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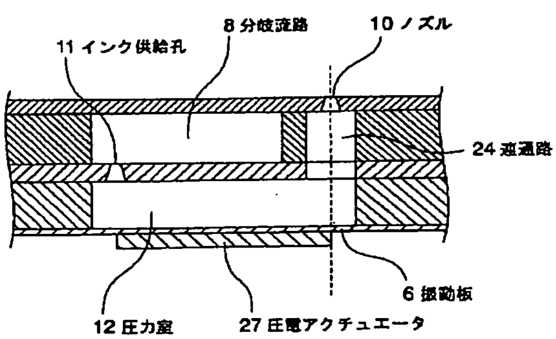

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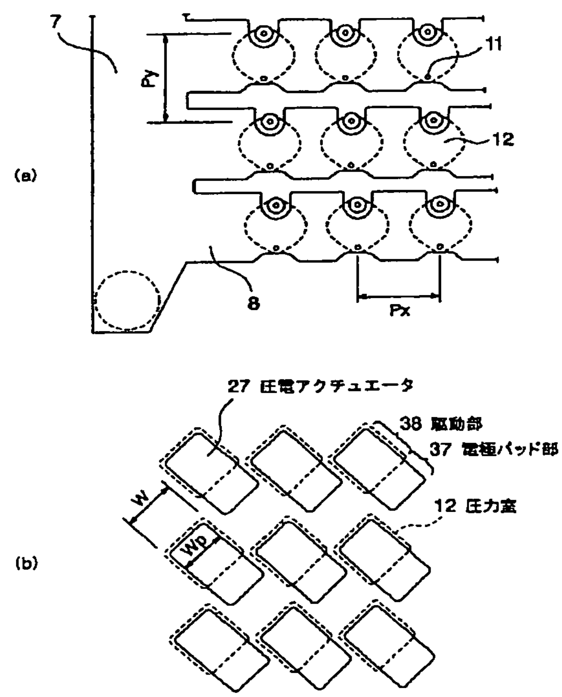

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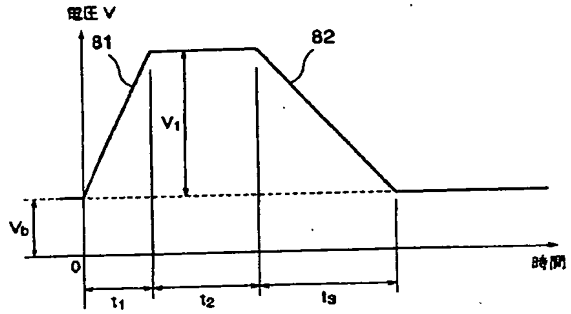

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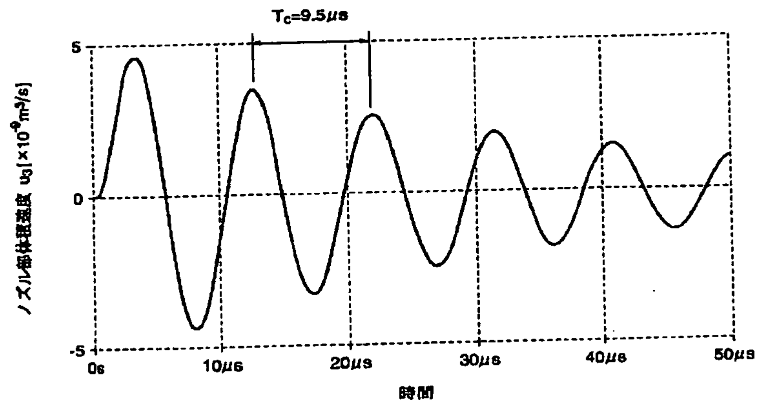

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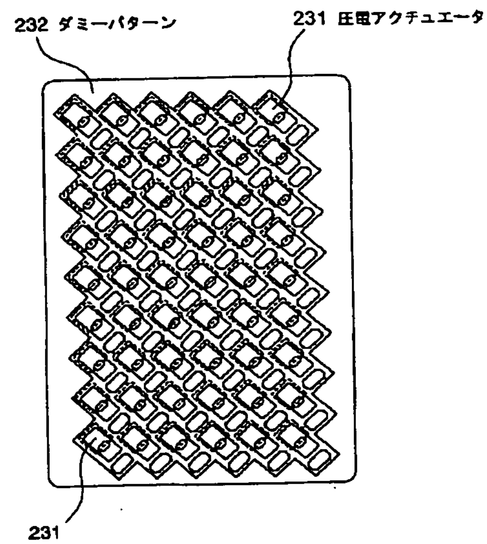

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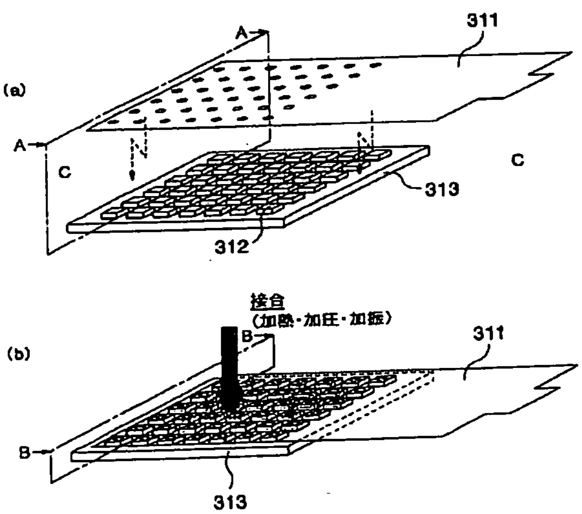

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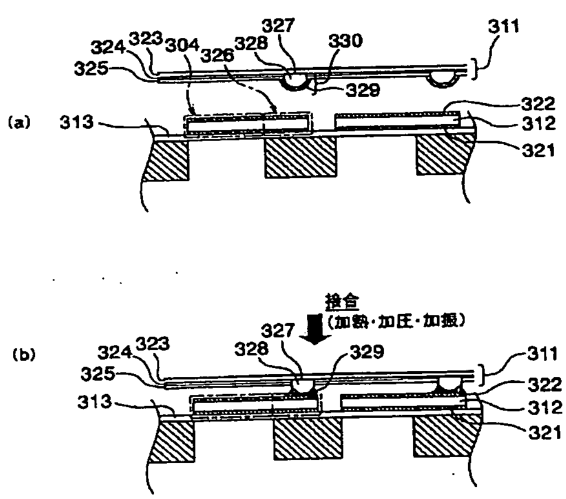

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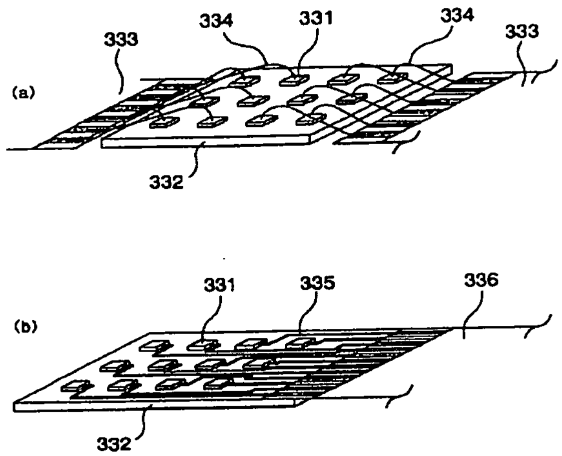

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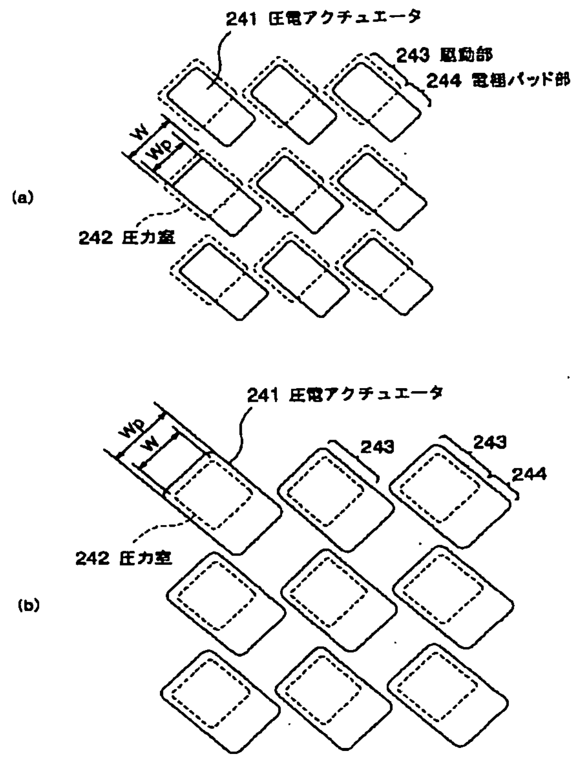

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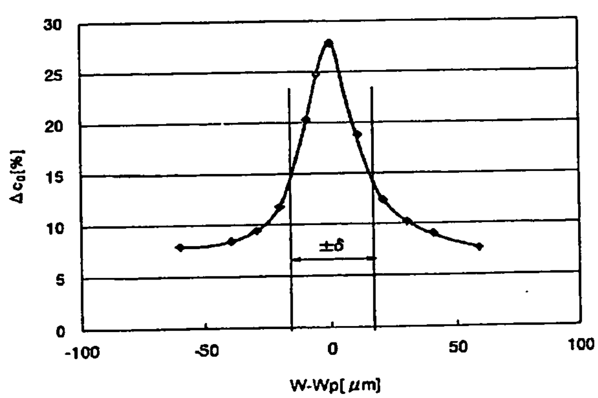

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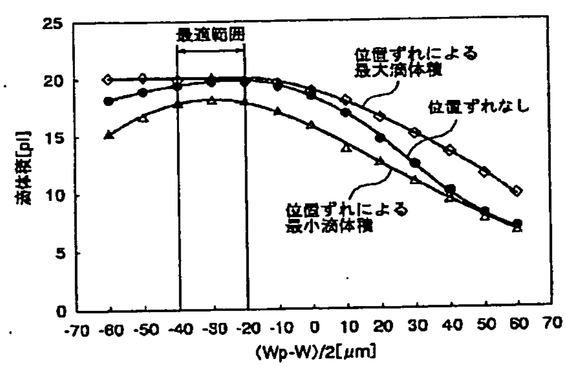

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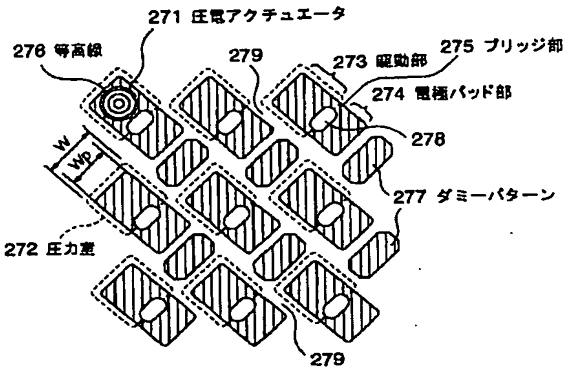

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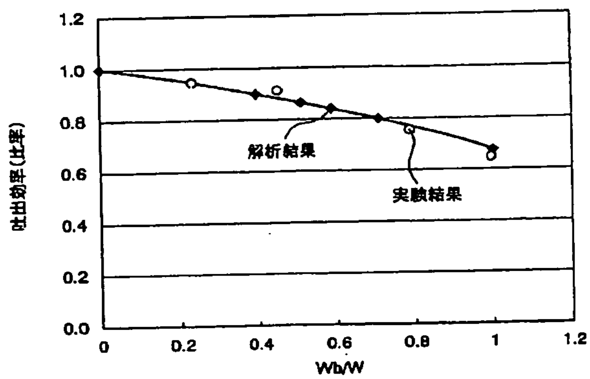

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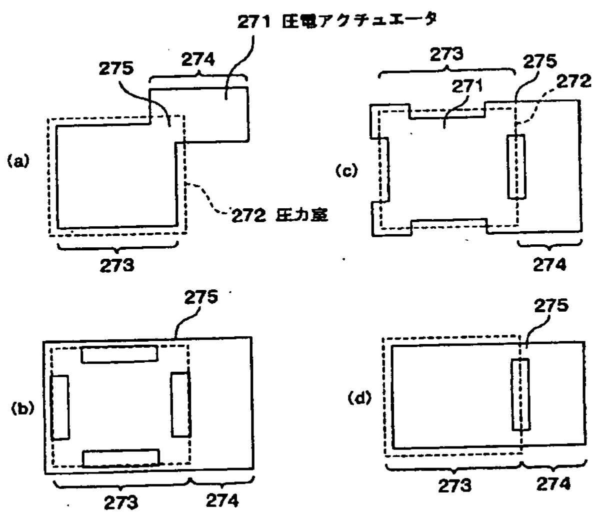

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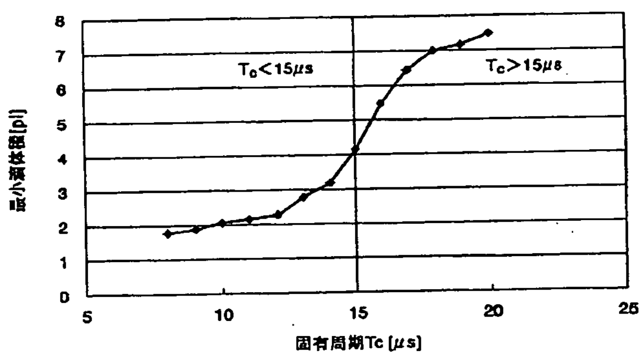

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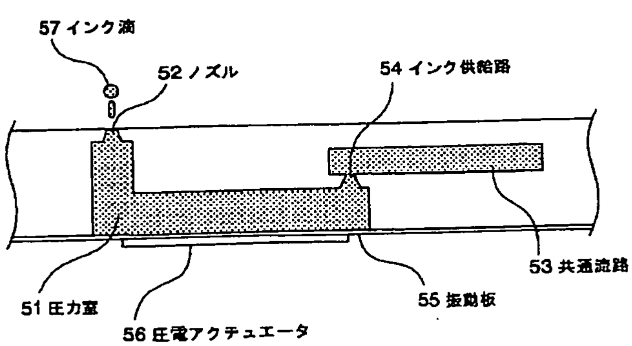

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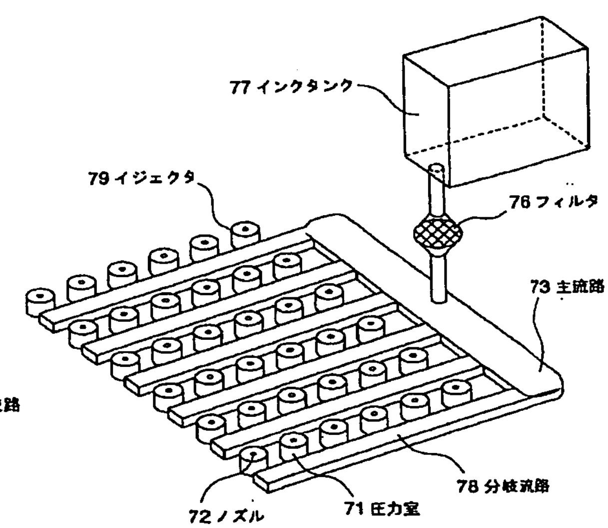

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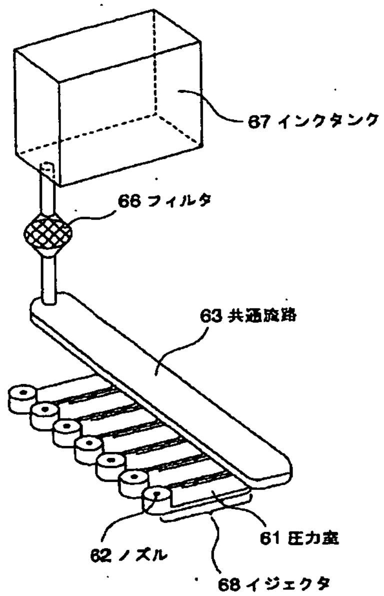

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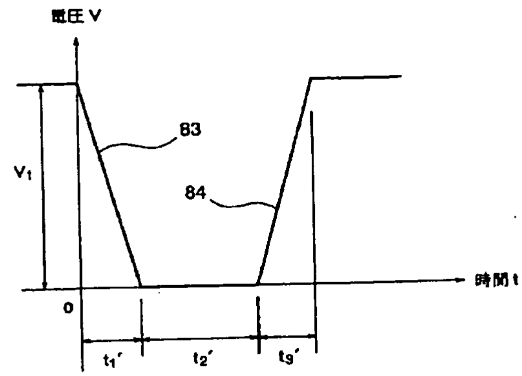

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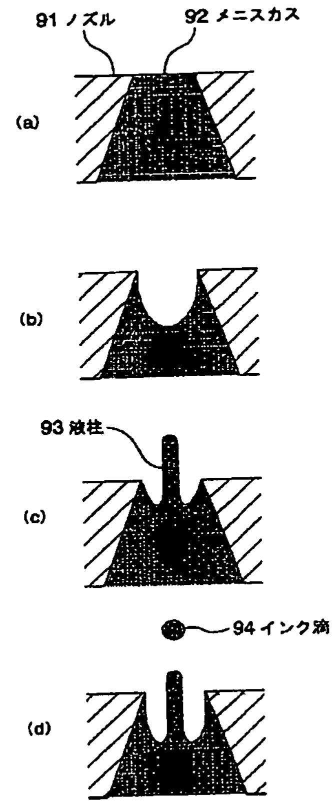

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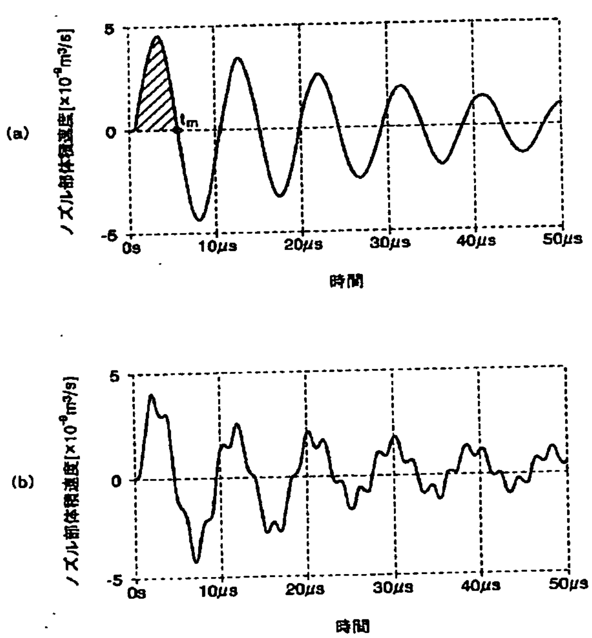

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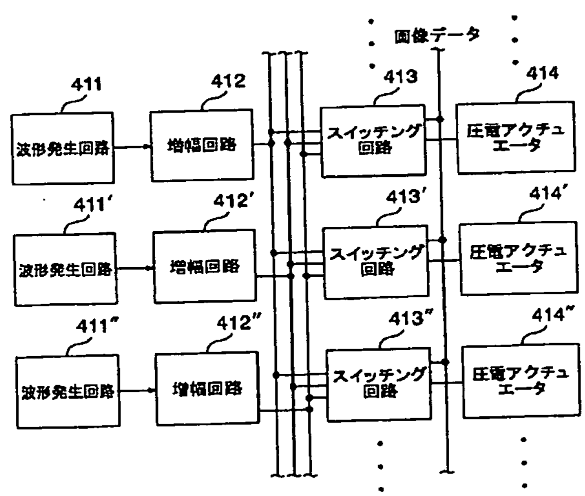

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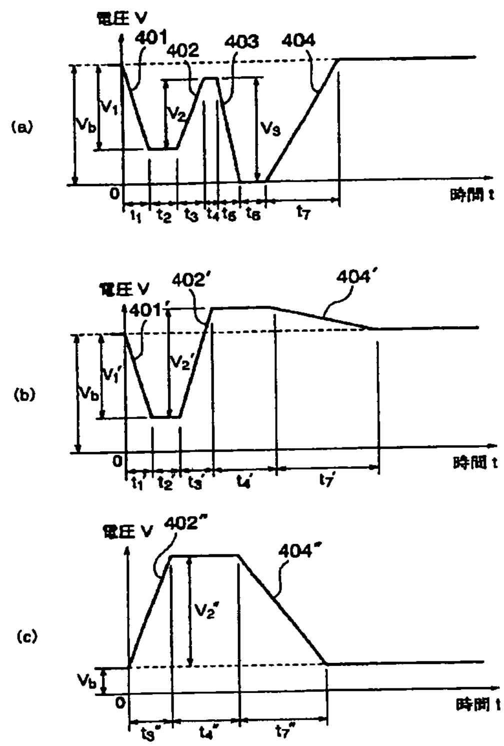

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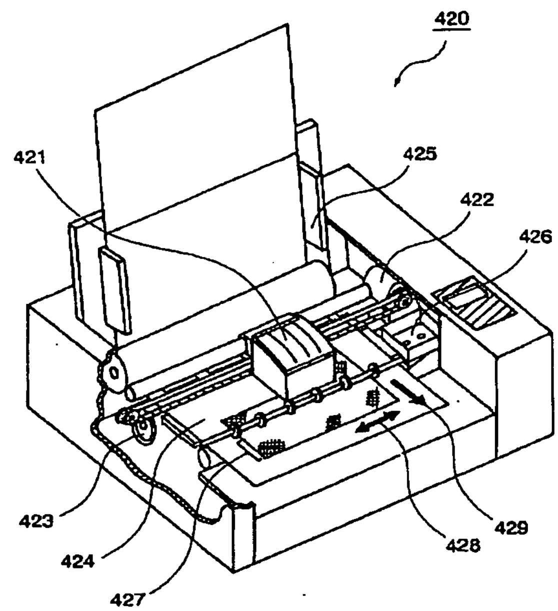

フロントページの続き

Ｆターム(参考)　2C057 AF06 AF36 AF38 AF39 AF40
AF41 AF51 AF78 AG16 AG44
AG52 AG85 AG90 AM15 AM21
AM22 AP22 AP25 AQ03 AR06
AR08 BA03 BA14 CA01

* NOTICES *

1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

CLAIMS

[Claim(s)]
[Claim 1] A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By generating a pressure wave in the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up The ink jet recording head characterized by being the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle, and the acoustic capacitance of said oscillating element being more than 2.0x10-20m5/N.
[Claim 2] The ink jet recording head according to claim 1 characterized by setting the acoustic capacitance of said oscillating element below to 5.5x10-19m5/N.
[Claim 3] The ink jet recording head according to claim 1 or 2 which answers the control of a driver voltage wave impressed to said oscillating element, and is characterized by the drop volume of the ink droplet which carries out the regurgitation from said nozzle changing to a multistage story.
[Claim 4] An ink jet recording head given in claim 1 characterized by the maximum drop volume of the ink droplet breathed out from said nozzle being 15 or more pls thru/or any 1 term of 3.
[Claim 5] The ink jet recording head according to claim 4 characterized by said driver voltage wave impressed at the time of the regurgitation of said ink droplet of 15 or more pls including the 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which shrinks the volume of said pressure room, and making an ink droplet breathing out, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.
[Claim 6] An ink jet recording head given in claim 1 characterized by the minimum drop volume of the ink droplet breathed out from said nozzle being 4 or less pls thru/or any 1 term of 5.
[Claim 7] The 1st electrical-potential-difference change process that said driver voltage wave impressed at the time of the regurgitation of said ink droplet of 4 or less pls impresses an electrical potential difference in the direction which expands the volume of said pressure room, It is characterized by including the 2nd electrical-potential-difference change process for impressing an electrical potential difference in the direction which compresses the volume of said pressure room, forming the liquid column of a path smaller than the diameter of opening of this nozzle in said nozzle, making an ink droplet separate from the head of this liquid column, and performing the regurgitation of a minute ink droplet. An ink jet recording head according to claim 6.
[Claim 8] An ink jet recording head given in claim 1 characterized by setting the aspect ratio in said pressure room and each flat-surface configuration of an electrostrictive actuator as abbreviation 1, respectively thru/or any 1 term of 7.
[Claim 9] The ink jet recording head according to claim 8 which the flat-surface dimension (plane area) of said pressure room is set as 2 0.09-0.5mm, and is characterized by setting the thickness of said diaphragm and an electrostrictive actuator as 5-20 micrometers and 15-40 micrometers, respectively.

[Claim 10] An ink jet recording head given in claim 1 to which the flat-surface configuration of said oscillating element is characterized by being an abbreviation equilateral triangle, an abbreviation square, an approximate regular hexagon, or an approximate circle form thru/or any 1 term of 9.
[Claim 11] The oscillating element which has the flat-surface configuration of said abbreviation equilateral triangle, an abbreviation square, or an approximate regular hexagon is an ink jet recording head according to claim 10 characterized by forming a part for the joint of two sides each which adjoins mutually in the shape of a curve.
[Claim 12] When width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room, and the core of the actuator of said electrostrictive actuator, they are degree type Wp<= (W-2delta) or Wp>= (W+2delta).
An ink jet recording head given in claim 8 characterized by being satisfied thru/or any 1 term of 11.
[Claim 13] When width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room, and the core of the actuator of said electrostrictive actuator, it is degree type 0.9(W-2delta) <=Wp<= (W-2delta).

An ink jet recording head given in claim 8 characterized by being satisfied thru/or any 1 term of 11.
[Claim 14] An ink jet recording head given in claim 1 characterized by setting up the acoustic capacitance of said oscillating element more greatly than the acoustic capacitance of said pressure room thru/or any 1 term of 13.
[Claim 15] if the inertance of cc and said oscillating element is set [the natural period of the pressure wave generated in said pressure interior of a room] to m0 for the synthetic acoustic capacitance of Tc, said oscillating element, and a pressure room -- a degree type -- m0<2.5x10-4Tc2/cc [kg/m4]
An ink jet recording head given in claim 1 characterized by being satisfied thru/or any 1 term of 14.
[Claim 16] An ink jet recording head given in claim 1 to which the ink droplet breathed out from said nozzle is characterized by reaching the target on a record medium in the record resolution of 600 or less dpi thru/or any 1 term of 15.
[Claim 17] An ink jet recording head given in claim 1 characterized by setting the natural period of the pressure wave generated in said pressure interior of a room as 15 or less microseconds thru/or any 1 term of 16.
[Claim 18] An ink jet recording head given in claim 1 characterized by equipping said electrostrictive actuator with the actuator stationed to the field equivalent to said pressure room, the electrode pad section arranged to the field equivalent to the outer wall of said pressure room, and the bridge section which connects the both sides of said actuator and the electrode pad section thru/or any 1 term of 17.
[Claim 19] The ink jet recording head according to claim 18 characterized by connecting said bridge section with the location distant from the core of said actuator.
[Claim 20] An ink jet recording head given in claim 1 characterized by carrying out two-dimensional array of said nozzle to the shape of a matrix thru/or any 1 term of 19.
[Claim 21] An ink jet recording head given in claim 1 characterized by carrying out two-dimensional array of said pressure room and the oscillating element to the shape of a matrix thru/or any 1 term of 20.
[Claim 22] The ink jet recording head according to claim 21 characterized by arranging a dummy pattern so that the periphery section of the electrostrictive actuator field where two or more arrays of said electrostrictive actuator were carried out may be surrounded.
[Claim 23] The ink jet recording head according to claim 21 or 22 characterized by arranging said dummy pattern between said electrostrictive actuators in the interior of said electrostrictive actuator field.
[Claim 24] the slot which encloses the perimeter of said electrostrictive actuator -- having -- the width of face of this slot -- the perimeter of all electrostrictive actuators -- abbreviation -- an ink jet recording head given in claim 21 characterized by similarly being set up thru/or any 1 term of 23.
[Claim 25] An ink jet recording head given in claim 20 which it has the wiring substrate with which the signal line was formed, and this wiring substrate is arranged in a wrap location in the upper part of said

electrostrictive actuator by which two-dimensional array was carried out to the shape of a matrix, and is characterized by connecting said electrostrictive actuator and wiring substrate electrically through a bump thru/or any 1 term of 24.

[Claim 26] The ink jet recording head according to claim 25 characterized by constituting said bump with conductive core material and the jointing material for corrugated fibreboard which carried out the coat to the periphery section of this core material.

[Claim 27] The ink jet recording head according to claim 26 characterized by forming said core material in the shape of a semi-sphere.

[Claim 28] An ink jet recording head given in claim 25 characterized by said wiring substrate containing a resin base material and a metallic conductor thru/or any 1 term of 27.

[Claim 29] An ink jet recording head given in claim 1 characterized by the member which forms said nozzle consisting of resin films thru/or any 1 term of 28.

[Claim 30] The manufacture approach of the ink jet recording head which is the manufacture approach of manufacturing the ink jet recording head of a publication in claim 1 thru/or any 1 term of 29, and is characterized by carrying out patterning of said electrostrictive actuator by sandblasting processing.

[Claim 31] The ink jet recording device characterized by equipping claim 1 thru/or any 1 term of 29 with the ink jet recording head of a publication.

[Claim 32] A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of setting up the acoustic capacitance of said oscillating element more than 2.0x10-20m5/N, impressing an electrical potential difference in the direction which makes said oscillating element contracting the volume of said pressure room, and making an ink droplet breathing out, The actuation approach of the ink jet recording head characterized by carrying out the regurgitation of the ink droplet of 15 or more pls by impressing a driver voltage wave including the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.

[Claim 33] A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which the acoustic capacitance of said oscillating element is set [direction] to more than 2.0x10-20m5/N and below 5.5x10-19m5-/N, and expands the volume of said pressure room to said oscillating element, By impressing an electrical potential difference in the direction which compresses the volume of said pressure room, and impressing a driver voltage wave including the 2nd electrical-potential-difference change process for forming the liquid column of a path smaller than the diameter of opening of this nozzle in said nozzle, making an ink droplet separate from the head of this liquid column, and performing the regurgitation of a minute ink droplet The actuation approach of the ink jet recording head characterized by carrying out the regurgitation of the ink droplet of 4 or less pls.

[Translation done.]

* NOTICES *

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the ink jet recording device which equipped with such an ink jet recording head the manufacture approach of an ink jet recording head and such an ink jet recording head of performing record of an alphabetic character or an image by the ink droplet which carries out the regurgitation and the actuation approach, and the list.
[0002]
[Description of the Prior Art] In recent years, very small [the noise at the time of record], the non impact recording method is attracting the interest at the point in which high-speed record is possible, and the ink jet printer which used the ink jet recording method also in it has spread widely. Such an ink jet printer makes an ink droplet fly from a recording head, is made to adhere to the recording paper, is equipped with the configuration which prints an alphabetic character, a graphic form, a photograph, etc. at high speed, and it can record it, without performing fixation processing special to a regular paper etc. The drop on-demand mold ink jet method which carries out the regurgitation of the ink droplet from the nozzle which is open for free passage in a pressure room by making the pressure room where it filled up with ink generate a pressure wave (acoustic wave), using electromechanical transducers, such as an electrostrictive actuator, as the above-mentioned ink jet recording method is learned.
[0003] The ink jet recording head which adopted the drop on-demand mold ink jet method is indicated by JP,53-12138,B, JP,10-193587,A, etc. Drawing 34 is the sectional view showing the recording head of the ink jet recording device indicated by these official reports. This ink jet recording device is equipped with the pressure room 51, the nozzle 52 which is open for free passage in the pressure room 51, the ink supply way 54 to which ink is led from an ink tank through the common passage 53, and the diaphragm 55 fixed to the base of the pressure room 51.
[0004] With the above-mentioned ink jet recording apparatus, a pressure wave is generated in the pressure room 51 by carrying out the variation rate (bending deformation) of the diaphragm 55, and producing volume change in the pressure room 51 by the electrostrictive actuator 56 prepared in the pressure room 51 exteriors, at the time of expulsion of an ink droplet. By this pressure wave, it is injected outside through a nozzle 52, and some ink with which it fills up in the pressure room 51 serves as an ink droplet 57, and it flies. The ink droplet which flew reaches the target on record media, such as the recording paper, and forms a record dot (pixel). By performing formation actuation of such a record dot repeatedly based on image data, an alphabetic character and an image are recorded on a record medium.
[0005] In the ink jet recording device of the above-mentioned drop mold on demand, there is a request of reconciling high-speed record and high-definition record. However, in the conventional ink jet recording device, it was very difficult to be compatible in high-speed record and high-definition record. For example, if resolution is low stopped for implementation of high-speed record, good image quality will be spoiled, and the request of the both sides of high-speed record and high-definition record has the relation of a trade-off as high-speed record will be barred, if resolution is highly set as reverse for

implementation of high-definition record.
[0006] Here, conditions required in order to reconcile the both sides of "high-speed record" and "high-definition record" with the above-mentioned ink jet recording device are explained. That is, when realizing "high-speed record", two, lowering of ** record resolution and increment (nozzle increased density) ** of the number of ** nozzles, become important conditions especially.
[0007] If "lowering of record resolution" of the above-mentioned condition ** is realized, since an unit area is recordable by few ink droplets, the time amount which record takes can be shortened. For example, in the case of 300dpi, if the record resolution of 300dpi (dots per inch) and the record resolution of 1200dpi are measured, the number of dots required to record the same area will become 1/16 [in the case of 1200dpi]. Here, if it assumes that the frequency (drive frequency) of expulsion of an ink droplet is the same, the direction in the case of recording by 300dpi will become possible [increasing a recording rate by about 16 times].
[0008] However, since image quality will deteriorate if record resolution is set up low, there is a minimum in reduction of record resolution. If it thinks from human being's vision property, in order to realize high-speed record, without spoiling image quality (quality of an alphabetic character or a line drawing), it is optimal to set up record resolution within the limits of 300 - 600dpi (however, 1 dots per inch = 39.37 dots/(meter)) extent. That is, the direction set as record resolution lower than the record resolution (700 - 2400dpi) of the ink jet recording device used for a current general target is advantageous when raising a recording rate. However, in order to set up record resolution low, it is necessary to realize the regurgitation of a big ink droplet according to it.
[0009] That is, in order to form the big dot corresponding to the high-speed record performed in low record resolution, the regurgitation of the ink droplet with the big drop volume must be carried out. Although the relation between record resolution and the necessary drop volume changes with ink and the record paper types to be used somewhat, in order to obtain record concentration sufficient in the record resolution of 300 - 600dpi, in the case of the common ink and the common record form which are used with the conventional ink jet recording device, the ink droplet volume of 15-30pl (pico liter) is needed (however, a 1pico liter = ten to 15 m3). This is 1.5 to 3 times the value of the ink droplet volume (about 10 pl(s)) needed by record resolution 1200dpi.
[0010] Moreover, in order to make a recording rate increase, said condition ** needs "to be increased by the number of nozzles." The number of dots which can be formed in per unit time amount increases, and a recording rate improves, so that there are many nozzles. Therefore, in the usual ink jet recording apparatus, many recording heads of the multi-nozzle mold which connected two or more ink regurgitation devices (ejector) mentioned above are used.
[0011] The recording head of the above-mentioned multi-nozzle mold is shown in drawing 35 . In this recording head, the ink tank 67 has connected with the common passage 63, and two or more pressure rooms 61 are connected with this common passage 63 through the ink supply way (not shown). Thus, the number of ejectors (the number of nozzles) can be increased to about 30-100 pieces by considering as the head structure of arranging an ejector 68 in one dimension to the common passage 63.
[0012] Moreover, the ink jet recording head (it is hereafter called a matrix-like array head) which considered as the head structure which can increase the number of ejectors further, and carried out two-dimensional array of the ejector to the shape of a matrix is indicated by for example, JP,1-208146,A, the Patent Publication Heisei No. 508808 [ten to] official report, etc. The matrix-like array head indicated by drawing 36 at these official reports is shown. With this matrix-like array head, common passage consists of the mainstream way 73 and the branching passage 78, and two or more ejectors 79 are connected to each of the branching passage 78. Such matrix-like array head structure is very advantageous to the increment in the number of ejectors (the number of nozzles). For example, 260 ejectors can be made to arrange, if the number of the branching passage 78 is made into 26 and it connects ten ejectors to each branching passage 78 at a time. In addition, 36 ejectors are displayed in drawing 36 .
[0013] As mentioned above, although the matrix-like array head is advantageous to the increment in the number of nozzles, if the array consistency of a pressure room is not set up highly, the size of the whole

recording head will increase, buildup of a head manufacturing cost, buildup of equipment size, or head mileage between services will increase, and the various problems of a recording rate falling will be caused. That is, the technical problem of making the number of nozzles increase by the ink jet recording head is how to be able to arrange many nozzles in a fixed area, that is, is transposed to the technical problem how a nozzle consistency can be increased. With a matrix-like array head as shown in drawing 36 , in order to make the array consistency of an ejector increase, it becomes an important technical problem to set up the size of a pressure room small.

[0014] It is desirable to, set up the path of the ink droplet which carries out the regurgitation on the other hand, as small as possible, in order for an ink jet recording device to realize "high image recording." In outputting a photograph especially, in order that the granular feeling of the highlights section (low concentration section) may influence image quality greatly, it is desirable to record the highlights section by the very small ink droplet. From the resolution of human being's eye, if the diameter of a dot is set to 40 micrometers or less, the granular feeling of an image will fall substantially, and since it will become difficult to carry out visual recognition of each dot if set to 30 more micrometers or less, image quality improves by leaps and bounds. Therefore, in the highlights section of an image, it must be desirable to realize the small dot of 30 micrometers or less of diameters, and, for that purpose, it must realize the regurgitation of the minute drop of 2 - 4pl extent.

[0015] The actuation approach for performing the minute drop regurgitation by the ink jet recording head is indicated by JP,55-17589,A. By the actuation approach given in this official report, a pressure room is once expanded just before the regurgitation, and the regurgitation of an ink droplet is performed from the condition which drew the meniscus of nozzle opening in the pressure room side. An example of an actuation wave used by this kind of the actuation approach is shown in drawing 37 . This actuation wave is constituted including the electrical-potential-difference change process 83 for expanding a pressure room, and the electrical-potential-difference change process 84 for compressing a pressure room subsequently and performing the regurgitation of an ink droplet.

[0016] Drawing 38 is the sectional view having shown typically the motion of the meniscus 92 in opening of the nozzle 91 at the time of impressing the actuation wave of drawing 37 . If the electrical-potential-difference change process 83 shown in drawing 37 is answered and a pressure room begins to expand although the meniscus 92 is carrying out the flat configuration by the initial state as shown in drawing 38 (a), when the center section of a meniscus 92 retreats more greatly than a periphery, a meniscus 92 will serve as a concave bend side configuration as shown in drawing 38 (b).

[0017] If the electrical-potential-difference change process 84 shown in drawing 37 is answered and a pressure room starts compression from the condition that the concave bend side meniscus 92 of the above was formed, as shown in drawing 38 (c), the thin liquid column 93 is formed in the center section of a meniscus 92, as further shown in drawing 38 (d), the point of a liquid column 93 will dissociate and an ink droplet 94 will be formed. The ink drop diameter at this time is almost equal to the size of the formed liquid column 93, and smaller than the diameter of a nozzle. That is, the regurgitation of the ink droplet 94 smaller than the diameter of a nozzle can be carried out by using such an actuation approach. As mentioned above, the thing of the actuation approach which controls the meniscus configuration in front of the regurgitation, and performs the minute drop regurgitation is hereafter called a "meniscus control system" on these descriptions.

[0018] As stated above, in order to realize "high-speed record" by the ink jet recording head of a drop mold on demand, the "large drop regurgitation" which enables low resolution record, and the "nozzle increased density" which enables the increment in the number of nozzles are required. On the other hand, in order to realize high-definition record, the "globule regurgitation" which enables granular feeling reduction of the highlights section is needed. Therefore, in order to reconcile the both sides of "high-speed record" and "high-definition record" by one recording head, it is necessary to satisfy simultaneously three conditions, the "large drop regurgitation", "nozzle increased density", and the "globule regurgitation."

[0019]

[Problem(s) to be Solved by the Invention] However, it is very difficult in the conventional ink jet

recording head to satisfy simultaneously all the "globule regurgitation" for realizing high-definition record in the "large drop regurgitation" for realizing high-speed record and "nozzle increased density", and a list.

[0020] Moreover, the unusual oscillation occurred in the meniscus at the time of expulsion of an ink droplet as another trouble in the conventional ink jet recording head, and there was a problem that the regurgitation phenomenon of an ink droplet destabilized. About the mechanism which an unusual meniscus oscillation generates, conventionally, no detailed examination is made and the prevention approach is not clarified, either. Below, it explains in accordance with the examination result by this invention persons.

[0021] Drawing 39 is a graph which shows an example of the observation of the meniscus oscillation observed by laser-doppler measurement, (a) is shown and (b) always [forward] shows the time of abnormalities, respectively. To originally a meniscus oscillation as shown in drawing 39 (a) being obtained, as shown in drawing 39 (b), the detailed oscillation was overlapped on the meniscus oscillation observed actually. If such a detailed oscillation is overlapped on a meniscus, the regurgitation of an ink droplet will become instability dramatically. In order to perform the regurgitation of a minute drop using oil-level interference of a meniscus, when the above-mentioned detailed oscillation is overlapped on a meniscus oscillation, it becomes impossible to expect the normal minute drop regurgitation -- the regurgitation of a minute drop becomes impossible or an unnecessary ink droplet is breathed out by reverse -- especially in the meniscus control system mentioned above.

[0022] This invention aims at providing with the manufacture approach of an ink jet recording head, and the actuation approach the ink jet recording apparatus which carried the ink jet recording head which can be made to be able to breathe out the "large drop" of necessary size from the same nozzle, and can realize "nozzle increased density", and can raise the expulsion-of-an-ink-droplet effectiveness per unit area, and such an ink jet recording head, and a list, avoiding enlargement and a cost rise of head size in view of the above.

[0023] Moreover, this invention makes the both sides of the "large drop" of necessary size, and a "globule" breathe out selectively from the same nozzle, and aims at offering the ink jet recording head which enables coexistence of high-speed record and high-definition record. Further, this invention prevents the shimmy of a meniscus and aims at realizing an ink jet recording head with high regurgitation stability.

[0024]

[Means for Solving the Problem] Although it is very difficult to be simultaneously satisfied with the conventional ink jet recording head of three conditions of "nozzle increased density" in addition to implementation of the "large drop regurgitation" from the same nozzle, and the "globule regurgitation", an example is explained below, citing the reason. First, considering the "large drop regurgitation", the volume of the maximum ink droplet which can carry out the regurgitation in an ink jet recording head is mostly in agreement with volume variation (excluded volume) deltaV which generates a pressure room so that it may mention later (refer to formula (2)). That is, it is necessary to make the pressure interior of a room generate a volume change almost equivalent to the ink droplet which carries out the regurgitation. Therefore, in order to obtain the big drop volume, it is necessary to increase the actuation area (area of base of a pressure room) of an electrostrictive actuator, and to increase deltaV.

[0025] For example, when the amount of displacement of an electrostrictive actuator is set to 0.1 micrometers, the regurgitation of drop volume 10pl can be performed in about two 1x10 to 7 m actuation area, but when you are going to make it increase the drop volume to 20pl(s), a twice [about] as many actuation area (2x10 to 7 m2) as this is needed. consequently, the number of nozzles per unit area (nozzle consistency) -- about -- it will decrease to one half. That is, if low resolution record tends to be realized and it is going to enlarge the drop volume for high-speed record, the size of a pressure room will increase and a nozzle consistency will fall as the result. Thus, since the "large drop regurgitation" and "nozzle increased density" have the relation of a trade-off, it is very difficult to realize simultaneously low resolution record and the increment in the number of nozzles (nozzle increased density).

[0026] Next, the "globule regurgitation" is considered. Since it is shown below in order for a meniscus control system to perform the minute drop regurgitation, it is necessary to set up short the natural period Tc of the pressure wave which the pressure interior of a room is made to generate. That is, with a meniscus control system, as drawing 38 explained, after drawing a meniscus 92 in a pressure room side first and making a meniscus 92 into a concave bend configuration, the thin liquid column 93 is formed by extruding a meniscus 92 toward a nozzle outside. It was shown clearly that the size of the liquid column which this invention persons examine the formation mechanism of a liquid column 93 in a detail, consequently is formed is dependent on the oil-level rate at the time of extruding a meniscus.
[0027] Drawing 32 is the sectional view having shown typically the behavior of the meniscus at the time of using a meniscus control system. Namely, if a pressure is applied in the direction extruded outside to the meniscus 92 of a concave bend side configuration, each part of a meniscus 92 tends to move in the direction of a normal of an oil level, as shown in drawing 32 (a). Consequently, a lot of ink focuses on a nozzle center section, and a liquid column 93 is formed in the center section of the nozzle 91 of this local increment in the volume. Since the increment rate in the volume in a nozzle center section also becomes large at this time so that the passing speed of an oil level is quick, the very thin liquid column 93 is formed with a quick growth rate. On the contrary, since the rate of the increment in the volume also becomes small as shown in drawing 32 (b) when the passing speed of an oil level is slow, a liquid column 93 becomes thick and a growth rate becomes small.
[0028] The drop diameter of the ink droplet 94 breathed out with a meniscus control system is mostly in agreement with the size of the liquid column 93 formed. Moreover, the flight rate (drop speed) of an ink droplet is mostly in agreement with the growth rate of a liquid column 93. Therefore, in order to make the minute ink droplet 94 fly at high speed, the above-mentioned oil-level passing speed is made to increase, and it becomes important conditions to produce the rapid increment in the volume in the nozzle center section. Here, the natural period Tc of a pressure wave is governing oil-level passing speed. That is, the velocity of vibration of the meniscus 92 at the time of expulsion of an ink droplet is dependent on the natural period Tc of a pressure wave, and it increases, so that a natural period Tc is short, the velocity of vibration, i.e., the oil-level passing speed, of a meniscus. Therefore, when carrying out the regurgitation of the minute drop with a meniscus control system, it becomes so advantageous that the natural period Tc of a pressure wave is short.
[0029] Drawing 33 is a graph which indicates the result of having investigated relation with the natural period Tc of a pressure wave to be the minimum drop diameter acquired with a meniscus control system. This graph shows that the minimum drop diameter decreases, so that a natural period becomes short. Although it is dependent on the diameter of a nozzle, ink viscosity, etc., the minimum ink droplet volume obtained needs to set a natural period Tc as 12 or less microseconds still more desirably 15 or less microseconds by the general ink jet recording head whose viscosity of the ink which the diameter of a nozzle is 20-30 micrometers, and uses is 2-5cps, in order to make possible the regurgitation [the minute drop of 2-4pl suitable for high-definition record].
[0030] However, the "large drop regurgitation" and reciprocity relation which were described previously have reduction of a natural period Tc. That is, if the size of a pressure room is greatly set up in order to realize the "large drop regurgitation", the natural period of a pressure wave will become very long. This is because a natural period Tc becomes long depending on the acoustic capacitance sum (c0+c1) of a pressure room and an oscillating element (diaphragm + electrostrictive actuator) with the big pressure room and big oscillating element of size suitable for the "large drop regurgitation" as for the natural period Tc of a pressure wave. For example, although it is easy to realize the ink jet recording head whose large drop volume is 10pl(s) and whose natural period is 10 microseconds, if it is going to increase the large drop volume to 20pl(s), a natural period Tc will be set to about 20 twice [about] as many microseconds as this.
[0031] Then, this invention persons receive having performed adjustment of the drop volume and a natural period Tc conventionally, combining the parameter of a large number in connection with head structure by trial and error. In the ink jet recording head using the electrostrictive actuator which bends and deforms from various experimental results That the substantial parameter which governs the drop

volume and a natural period Tc is only the acoustic capacitance of an oscillating element by specifying the range where the acoustic capacitance of a header and an oscillating element is proper It came to invent this invention which realizes coexistence and "nozzle increased density" of the "large drop regurgitation" of necessary size, and the "globule regurgitation."
[0032] In order to attain the above-mentioned object, the ink jet recording head concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By generating a pressure wave in the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up It is the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle, and acoustic capacitance of said oscillating element is characterized by being more than 2.0x10-20m5/N.
[0033] The acoustic capacitance (c0) of an oscillating element is a parameter showing the rigidity of an oscillating element, an oscillating element tends to bend, namely, that c0 is large means that it is easy to generate the big excluded volume of a pressure room. The value of various experimental results and structural-analysis results which are mentioned later to 2.0x10-20m5/N can be said to be the value optimal as a lower limit of acoustic capacitance c0 from a viewpoint that the regurgitation of the "large drop" of 15 or more pls required for low resolution record of 600 or less dpi is realizable.
[0034] For example, characterization was carried out to each about the example which changed variously thickness tp of an electrostrictive actuator, the thickness tv of a diaphragm, and the pressure room width of face W. Consequently, acoustic capacitance c0 >=2.0x10-20[m5/N]
although the regurgitation of the "large drop" of 15 or more pls was able to be carried out under ******
-- acoustic capacitance c -- 0< 2.0x10-20 [m5/N]
Under ******, the regurgitation of the "large drop" of 15 or more pls could not be carried out, and sufficient image concentration was not able to be obtained.
[0035] That is, in this invention, by having specified the acoustic capacitance c0 of an oscillating element more than 2.0x10-20m5/N, the excluded volume of 15 or more pls by the oscillating element can be obtained, and the regurgitation of the large drop of 15 or more pls can be carried out from one nozzle.
[0036] It is desirable to set the upper limit of the acoustic capacitance of an oscillating element as 5.5x10-19m5/N in the desirable ink jet recording head of this invention. Although this invention persons could realize the "large drop regurgitation" by setting acoustic capacitance c0 as the value more than 2.0x10-20m5/N, when acoustic capacitance c0 was too large, the natural period of the pressure wave generated in the pressure interior of a room increased, and they confirmed that the evil of it becoming impossible to perform the "globule regurgitation" occurred. And based on the various experimental results mentioned later, it hit on an idea by setting the upper limit of acoustic capacitance c0 as 5.5x10-19m5/N to prevent generating of the above-mentioned evil.
[0037] For example, although the "large drop" of 15 or more pls was able to carry out the regurgitation when the regurgitation experiment was conducted under the conditions of acoustic capacitance c0>5.5x10-19m5/N, the regurgitation of the "globule" of 4 or less pls was not able to be carried out. In order to secure large drop volume of 15 or more pls and to obtain globule volume of 4 or less pls from this result, it checked that it was optimal to set the acoustic capacitance c0 of an oscillating element to more than 2.0x10-20m5/N and below 5.5x10-19m5/N.
[0038] In the desirable ink jet recording head of this invention, the control of a driver voltage wave impressed to said oscillating element is answered, and the drop volume of the ink droplet which carries out the regurgitation from said nozzle changes to a multistage story. In this case, since the low resolution record by the large drop and the high-definition record by the globule are simultaneously realizable, the effectiveness that it is compatible in high-speed record and high-definition record is acquired.
[0039] Moreover, it is desirable that the maximum drop volume of the ink droplet which carries out the regurgitation from said nozzle is set as 15 or more pls. In this case, since it becomes possible to set record resolution as 600 or less dpi, the effectiveness that a recording rate can be increased is acquired.

The driver voltage wave impressed at the time of the regurgitation of the ink droplet of 15 or more pls should be constituted including at least the 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which shrinks the volume of said pressure room, and making an ink droplet breathing out, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.

[0040] Or it is also a desirable mode that the minimum drop volume of the ink droplet breathed out from said nozzle is 4 or less pls. In this case, in the highlights section, the low smooth image recording of graininess becomes possible, and the effectiveness that high-definition record is realizable is acquired. The driver voltage wave impressed at the time of the regurgitation of the ink droplet of 4 or less pls The 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room, By forming the liquid column which impresses an electrical potential difference in the direction which compresses the volume of said pressure room, and has a path smaller than the diameter of opening of said nozzle in said nozzle, and making an ink droplet separate from the head of this liquid column It should constitute including the 2nd electrical-potential-difference change process for performing the regurgitation of a minute ink droplet at least.

[0041] Furthermore, the aspect ratio in said pressure room and each flat-surface configuration of an electrostrictive actuator is preferably set as abbreviation 1, respectively. The "aspect ratio" in this invention means the ratio of the longest width of face in the flat-surface configuration of an oscillating element, and the shortest width of face. If an aspect ratio is set as abbreviation 1, the regurgitation effectiveness per unit area can be maximized and it will become possible to realize an ink jet recording head with a high nozzle consistency. As a flat-surface configuration of an oscillating element, it can choose any of an abbreviation equilateral triangle, an abbreviation square, an approximate regular hexagon, and an approximate circle form they are.

[0042] It is desirable to set the flat-surface dimension (plane area) of a pressure room as 2 0.09-0.5mm, and to set the thickness of a diaphragm and an electrostrictive actuator as 5-20 micrometers and 15-40 micrometers here, respectively. Thereby, in the ink jet recording head in which an aspect ratio has the pressure room of abbreviation 1, the acoustic capacitance c0 of an oscillating element can be set to more than 2.0x10-20m5-/N and below 5.5x10-19m5-/N, and the effectiveness that it is compatible in the "large drop regurgitation" and the "globule regurgitation" is acquired.

[0043] Here, as for the acoustic capacitance of an oscillating element, it is desirable to be set up more greatly than the acoustic capacitance of a pressure room. In this case, the shimmy of a meniscus can be controlled, an oscillation of a meniscus can be normalized and the effectiveness that the stability of expulsion of an ink droplet can be improved can be acquired.

[0044] moreover -- if the inertance of cc and said oscillating element is set [the natural period of the pressure wave generated in said pressure interior of a room] to m0 for the synthetic acoustic capacitance of Tc, said oscillating element, and a pressure room -- a degree type -- m0<2.5x10-4Tc2/cc [kg/m4]

It is a desirable mode that it is also satisfied. Excitation of the vibration system which is inherent in an ink jet recording head can be controlled by this, the effect of the above-mentioned meniscus shimmy can be controlled further, and it becomes possible to realize the ink jet recording head excellent in regurgitation stability.

[0045] When width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room, and the core of the actuator of said electrostrictive actuator, they are degree type Wp<= (W-2delta) or Wp>= (W+2delta).

It is desirable that it is satisfied. In this case, the support condition of an electrostrictive actuator edge becomes always fixed, and the robustness (insensibility) over a location gap of an electrostrictive actuator improves.

[0046] Moreover, when width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room,

and the core of the actuator of said electrostrictive actuator, it is degree type 0.9(W-2delta) <=Wp<= (W-2delta).

It is a desirable mode that it is also satisfied. Thereby, even when junction location gap occurs between an electrostrictive actuator and a pressure room, it can prevent that the big change in regurgitation effectiveness arises, and it becomes possible to secure still higher regurgitation effectiveness.

[0047] It is desirable that the ink droplet breathed out from said nozzle reaches the target on a record medium in the record resolution of 600 or less dpi. In this case, since quality, such as an alphabetic character recorded, is also securable while the number of dots which is needed for record can be lessened and it becomes advantageous to high-speed record, the effectiveness that coexistence of high-speed record and high-definition record is attained is acquired. Moreover, it is also a desirable mode that the natural period Tc of the pressure wave generated in said pressure interior of a room is set as 15 or less microseconds. In this case, it becomes possible to carry out the regurgitation of the small ink droplet of a path with a meniscus control system, and the effectiveness that image quality can be improved is acquired in the output of a photograph etc.

[0048] Moreover, it is also a desirable mode that said electrostrictive actuator is equipped with the actuator stationed to the field equivalent to said pressure room, the electrode pad section arranged to the field equivalent to the outer wall of said pressure room, and the bridge section which connects the both sides of said actuator and said electrode pad section. The phenomenon in which deformation of an electrostrictive actuator is barred by the electrode pad section can be controlled by this, and it becomes possible to realize an ink jet recording head with high regurgitation effectiveness. If said bridge section is connected with the location distant from the core of said actuator, the restraint over deformation of said actuator can be minimized and the effectiveness that the regurgitation effectiveness of a head can be increased can be acquired.

[0049] Moreover, it is also a desirable mode that two-dimensional array of said nozzle is carried out to the shape of a matrix. In this case, since it becomes possible to increase the number of nozzles in a head, the effectiveness that a recording rate can be increased substantially is acquired.

[0050] A dummy pattern is arranged so that the periphery section of the electrostrictive actuator field where two or more arrays of the electrostrictive actuator were carried out may be surrounded preferably. Thereby, in case an electrostrictive actuator is processed by the sandblasting processing method, aggravation of the process tolerance resulting from side etching can be prevented, and the effectiveness that an ink jet recording head with the high homogeneity of a regurgitation property is realizable is acquired. A dummy pattern can be arranged also between the electrostrictive actuators in the interior of an electrostrictive actuator field. In this case, the effectiveness that the effect of the above-mentioned side etching can be controlled further is acquired.

[0051] In the desirable ink jet recording head of this invention, it has the wiring substrate with which the signal line was formed, this wiring substrate is arranged in a wrap location in the upper part of said electrostrictive actuator by which matrix arrangement was carried out two-dimensional, and said electrostrictive actuator and said wiring substrate are electrically connected through the bump. Thereby, also in the matrix-like array head which carried out the high density array, positive electrical connection becomes possible to each electrostrictive actuator. That is, since a signal line can be arranged to a plane different from an oscillating element, arrangement of a signal line does not spoil the high density array of a pressure room, and the high density array of a pressure room is attained.

[0052] Moreover, it is desirable that said bump is constituted with conductive core material and the jointing material for corrugated fibreboard which carried out the coat to the periphery section of this core material. In this case, since it becomes possible to form a gap between an electrostrictive actuator and a wiring substrate after electrical connection, the poor property of the electrostrictive actuator resulting from contact to an electrostrictive actuator and a wiring substrate can be prevented, and a reliable ink jet recording head can be realized. Furthermore, it is desirable that said core material is formed in the shape of a semi-sphere. In this case, the contact condition of an electrostrictive actuator and a bump can be equalized, and while the stable electrical connection becomes possible, the effectiveness that destruction of the electrostrictive actuator at the time of electrical connection can be

prevented is acquired. As for said wiring substrate, it is desirable that a resin base material and a metallic conductor are included. In this case, the contact condition of an electrostrictive actuator and a bump can be equalized further.
[0053] The manufacture approach of the ink jet recording head concerning this invention is the manufacture approach of manufacturing said ink jet recording head, and is characterized by carrying out patterning by sandblasting processing of said electrostrictive actuator.
[0054] By the manufacture approach of the ink jet recording head concerning this invention, since patterning of an electrostrictive actuator is performed by sandblasting processing, the electrostrictive actuator of a complicated configuration suitable for maximization and electrical connection of regurgitation effectiveness is realizable with close dimensional accuracy and a low manufacturing cost.
[0055] The ink jet recording apparatus concerning this invention is characterized by having said ink jet recording head. According to such an ink jet recording apparatus, an ink jet recording apparatus compatible in a high recording rate and high drawing quality is realizable.
[0056] The actuation approach of the ink jet recording head of the 1st view concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of setting up the acoustic capacitance of said oscillating element more than 2.0x10-20m5/N, impressing an electrical potential difference in the direction which makes said oscillating element contracting the volume of said pressure room, and making an ink droplet breathing out, It is characterized by carrying out the regurgitation of the ink droplet of 15 or more pls by impressing a driver voltage wave including the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.
[0057] By the actuation approach of the ink jet recording head of the 1st view of this invention, the effectiveness that the regurgitation of an ink droplet with the big drop volume which is needed for low resolution record of 600 or less dpi is realizable good is acquired.
[0058] The actuation approach of the ink jet recording head of the 2nd view concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which the acoustic capacitance of said oscillating element is set [direction] to more than 2.0x10-20m5/N and below 5.5x10-19m5-/N, and expands the volume of said pressure room to said oscillating element, By impressing an electrical potential difference in the direction which compresses the volume of said pressure room, and impressing a driver voltage wave including the 2nd electrical-potential-difference change process for forming the liquid column of a path smaller than the diameter of opening of this nozzle in said nozzle, making an ink droplet separate from the head of this liquid column, and performing the regurgitation of a minute ink droplet It is characterized by carrying out the regurgitation of the ink droplet of 4 or less pls.
[0059] By the actuation approach of the ink jet recording head of the 2nd view of this invention, the effectiveness that image recording with the low high drawing quality of graininess is realizable is acquired.
[0060]
[Embodiment of the Invention] It precedes explaining the example of an operation gestalt of the ink jet

recording head concerning this invention, and the relation between the operating characteristic of an oscillating element and the ink droplet volume is explained first. That is, although it is a mechanical system since an oscillating element generates a physical oscillation when it is seen in phenomenon, the ink jet recording head is intermingled for them and equipped with the acoustical system of ink passage, and the electric system of an actuation circuit besides the mechanical system. Since the differential equation description is a highly uniform, equivalent transformation of the these 3 system can be carried out mutually. Therefore, all are unified into an acoustical system here and actuation of a recording head is considered as one acoustic circuit.

[0061] A mechanical system can express the operating characteristic of an oscillating element (diaphragm + electrostrictive actuator) only with mass [kg], compliance [m/N], and three parameters of attenuation [Ns/m]. If equivalent transformation of these is carried out to an acoustical system, the operating characteristic of an oscillating element can be expressed only with an inertance m0 [kg/m4], acoustic capacitance c0 [m5/N], and three parameters of acoustic resistance r0 [Ns/m5].

[0062] If the above-mentioned acoustical system parameter is used, one oscillating element can be expressed as an equal circuit (acoustic circuit) shown in drawing 1 . Here, psi expresses a pressure [Pa]. Moreover, drawing 2 (a) is the equal circuit which connected the passage system with the oscillating element, and transposes the ink jet recording head shown in drawing 34 to an equal circuit.

[0063] It is here, and in an oscillating element and 1, a pressure room and 2 mean an ink supply way, and 3 means [u / [m3/s], volume velocity, and 0 of a subscript] the nozzle, respectively. Head properties, such as ink droplet volume, drop speed, and a natural period of a pressure wave, can be searched for by analyzing this circuit using a circuit simulator etc. and investigating change of the volume velocity u3 of the nozzle section.

[0064] Drawing 3 (a) - (c) is the result of investigating the relation between the acoustic capacitance c0 of an oscillating element, an inertance m0 and acoustic resistance r0, and excluded volume deltaV using the equal circuit of drawing 2 (a), respectively. In addition, excluded volume deltaV is a parameter which is mostly in agreement with the drop volume q so that it may mention later. From this result, to hardly affecting excluded volume deltaV (drop volume q), c0 is large to deltaV, m0 and r0 influenced, and the inclination which deltaV increases became clear, so that c0 was large. That is, it became clear that only c0 influences a regurgitation property (drop volume q) among the acoustic capacitance c0 of an oscillating element, an inertance m0, and acoustic resistance r0.

[0065] Since the inertance m0 and acoustic resistance r0 of an oscillating element cannot have big effect on a regurgitation property (drop volume) and the acoustic capacitance c3 of a nozzle can also be disregarded to the acoustic capacitance c0 of an oscillating element, and the acoustic capacitance c1 of a pressure room, the circuit of drawing 2 (a) can be simplified like drawing 2 (b). Here, it assumes that the relation of m2=k-m3 and r2=k-r3 is realized, and when theoretical analysis is performed about the case where the step-function-pressure psi is inputted, the volume velocity u3 in the nozzle section is expressed to the inertance and acoustic resistance in a nozzle and a supply way like a degree type.

[0066]

[Formula 1]

$$u_3(t)=\frac{c_0\,\psi}{cm_3\,E_c}\exp(-D_c\cdot t)\sin(E_c\cdot t) \qquad (1)$$

$$c=c_0+c_1$$

$$E_c=\sqrt{\frac{1+\frac{1}{k}}{cm_3}-D_c^2}$$

$$D_c=\frac{r_3}{2m_3}$$

[0067] Since volume [of the ink droplet (large drop) breathed out from a nozzle] q [m3] is almost equal to the area of the slash section shown in drawing 39 (a), q is expressed by the degree type.
[0068]
[Formula 2]

$$q=\int_0^{tm} u_3\, dt \qquad (2)$$

$$\approx 2\frac{m_2}{m_2+m_3}\cdot V\cdot\phi\cdot c_0$$

$$=2\frac{m_2}{m_2+m_3}\cdot \Delta V$$

[0069] phi [Pa/V] is an electroacoustic transduction multiplier (= psi/V), and is a parameter showing the magnitude of the pressure generated in per unit electrical potential difference. In the ink jet recording head using the electrostrictive actuator which carries out bending deformation, this electroacoustic transduction multiplier phi is a very important parameter which influences the drop volume (regurgitation effectiveness). However, about the relation between head structure and phi, there is no example investigated in detail in the past. Then, this invention persons investigated about the relation between head structure and phi by structural analysis which used the finite element method.
[0070] What is necessary is just to use the following approaches, in order to ask for phi by structural analysis. First, an oscillating element is modeled and the deformation condition of the oscillating element at the time of impressing applied voltage V is searched for. Next, a pressure is applied to an oscillating element and it asks for the pressure p required in order to return the deformation of an oscillating element to zero. Based on the value of this p, the value of phi is calculated as phi=p/V. Moreover, the acoustic capacitance c0 of an oscillating element is similarly computed as c0=deltaV/p by asking for excluded volume deltaV generated when a pressure p is applied and an oscillating element is made to deform.
[0071] Drawing 4 (a) is a graph which shows the result of having changed each parameter in connection with head structure in the large range, having performed structural analysis, and having calculated the value of c0 and phi. It is the range of 9x10-8 to 1x10 to 6 m2 about a pressure room and the area in the plane view of an electrostrictive actuator, and, specifically, the aspect ratio in a pressure room and the flat-surface configuration of each electrostrictive actuator was changed in 1-20. Moreover, in metal plates, such as stainless steel, it changed in 5-20 micrometers, and diaphragm thickness was changed in 20-100 micrometers with the polyimide film. Furthermore, electrostrictive actuator thickness was changed in 10-50 micrometers, the piezoelectric constant was changed, respectively in the range of 1x10-10 - 3x10-10 m/V, structural analysis was performed to various combination, and the value of phi and c0 was calculated. Consequently, as for acoustic capacitance c0, it became clear that 1x10-21 - 5x10-18m5/N and phi changed in the range of 4x103 - 4x104 Pa/V.
[0072] The result of having investigated relation with phi-c 0 (the parameter which determines the drop volume per unit electrical potential difference; referring to said formula (2)), andc0 based on the above-mentioned analysis result is shown in drawing 4 (b). Although the relation between c0 and phi-c 0 is distributed within the limits of the slash section in a graph from this result, in order to obtain the big drop volume (big phi-c 0) as a generality, it is c0 >=2.0x10-20[m5/N].
It became clear that it is necessary to set up.
[0073] That is, in order to secure the big drop volume (regurgitation effectiveness) in the ink jet recording head which bent and used the deforming electrostrictive actuator, it is c0 >=2.0x10-20[m5/N].

** -- it becomes important conditions. Acoustic capacitance c0 is a parameter showing the rigidity of an oscillating element, an oscillating element tends to bend, namely, that c0 is large means that it is easy to generate big excluded volume deltaV. Moreover, the value of 2.0x10-20m5/N can be said to be the value for which it was suitable as a lower limit of acoustic capacitance c0 also from a viewpoint of

obtaining the large drop of 15 or more pls which enables low resolution record of 600 or less dpi so that it may state below.
[0074] When a diaphragm is constituted from metallic materials (stainless steel, nickel, etc.) and a piezoelectric constant is made into abbreviation 3x10-10 m/V as conditions the most suitable when producing a actual ink jet recording head, and general, the relation between c0 and phi-c 0 comes to be shown in drawing 5 and drawing 6 .
[0075] Another graph with which drawing 5 shows the relation between c0 and phi-c 0, and drawing 6 are the graphs to which a part of drawing 5 was expanded. That is, when diaphragm construction material and a piezoelectric constant were fixed, even if it changed values, such as diaphragm thickness, electrostrictive actuator thickness, and an aspect ratio, it became clear that the relation between c0 and phi-c 0 is plotted on about one curve. It means that this, i.e., phi among the parameters which govern the drop volume q, can be treated as a function of c0.
[0076] In a general ink jet recording head, m2 and m3 in said formula (2) are set up with m2**m3 so that it may mention later. Moreover, if applied voltage V considers an actuation circuit and power-source cost, about 40V will become an upper limit. Therefore, among the parameters of a formula (2), since m2/(m2+m3) and applied voltage V are parameters actually unchangeable into arbitration and phi is a parameter depending on c0, it can be said that the parameter which is governing the drop volume q is only c0 substantially.
[0077] Then, c0 [required to obtain drop volume of 15 or more pls from the result of drawing 6] is calculated. As mentioned above, since it can place with m2/(m2+m3) **1/2, and V<=40 [V], in order to secure drop volume of 15 or more pls, it is necessary to set up phi-c 0 more than 4x10-16m3/V. If this is applied to the graph of drawing 6 , it will become the conditions of c0 >=2.0x10-20m5/N. That is, c0 >=2.0x10-20m5/N serves as important conditions also from a viewpoint of obtaining drop volume of 15 or more pls which was suitable for low resolution record by the ink jet recording head which bent and used the deforming electrostrictive actuator.
[0078] As stated above, it bends and the point of having specified the header and the proper lower limit of c0 for the substantial parameter which governs the drop volume in the ink jet recording head using the deforming electrostrictive actuator being only c0 is one of the descriptions of this invention. It is very effective to have arranged the rule parameter only to one of the c0 as mentioned above, and to have clarified the optimal range to conventionally having adjusted the drop volume, combining the parameter of a large number in connection with head structure by trial and error, when performing the optimization design of a head.
[0079] Next, the pressure room configuration of reconciling the "large drop regurgitation" and "nozzle increased density" is considered. Since the parameter which is governing the drop volume substantially is only c0 as mentioned above, in order to reconcile the "large drop regurgitation" and "nozzle increased density", it is important to maximize c0 per unit area.
[0080] It depends for acoustic capacitance c0 on the configuration of an oscillating element greatly. Then, it investigated about the oscillating element configuration which can maximize c0 per unit area. Drawing 7 is the result of calculating c0 from each configuration from which area is the same as that of, and an aspect ratio (aspect ratio) differs about a square pressure room. Drawing 7 shows that acoustic capacitance c0 increases, so that the aspect ratio of the flat-surface configuration of a pressure room approaches 1 (i.e., so that it is a configuration near a square). That is, if the pressure room of a flat-surface configuration with the aspect ratio near 1 is used, it will become possible to obtain the big acoustic capacitance c0 in a small occupancy area, and will become advantageous to improvement in a nozzle consistency.
[0081] In order to set up the regurgitation effectiveness per unit area highly from the result shown in drawing 7 , it is required to set up the aspect ratio of a pressure room between 0.3-3 at least. Furthermore, it is desirable to set up an aspect ratio between 0.8-1.2. In this case, an aspect ratio = as compared with the optimum conditions of 1, decline in regurgitation effectiveness can be dedicated to 30% or less.
[0082] Here, an "aspect ratio" means the value which shows the ratio (B/A) of the longest width of face

(A) in the flat-surface configuration of a pressure room, and the shortest width of face (B), as shown in drawing 8 (a) - (d) explaining the definition of an aspect ratio. Moreover, when the aspect ratio of the flat-surface configuration of a pressure room is set as abbreviation 1, the aspect ratio of an oscillating element also usually serves as abbreviation 1. That is, the oscillating element consists of actuators (after-mentioned) of a diaphragm and an electrostrictive actuator, and since the actuator of an electrostrictive actuator is made into the flat-surface configuration of a pressure room, and a configuration mostly in agreement, the aspect ratio of an oscillating element also serves as abbreviation 1.
[0083] Although drawing 7 is the result of investigating about a square pressure room, the same result that c0 becomes max by aspect ratio =1 is obtained also about the polygon containing the other triangle, a pentagon, and a hexagon, and the ellipse form. Therefore, an aspect ratio = generally the conclusion that 1 is the optimal is appliable also about the pressure room of other configurations other than a square.
[0084] Next, the cause of the unusual meniscus oscillation shown in drawing 39 (b) is described. Drawing 9 is a graph which shows the result of having investigated the frequency response of the equivalence electrical circuit of drawing 2 (a). Since the peak exists in 130kHz and 1.3MHz in this graph, as for this circuit, it turns out that it has two resonance frequency. Drawing 10 is the circuit diagram which rewrote the equivalence electrical circuit of drawing 2 (a) and in which showing the equivalence electrical circuit of one ejector. When a circuit is rewritten in this way, it turns out that the two vibration system A and B is included in this circuit.
[0085] That is, it is possible that two resonance frequency looked at by drawing 9 is equivalent to each resonance frequency of vibration system A and B. It generates according to vibration system A, and the original meniscus oscillation used for expulsion of an ink droplet can understand generating of a meniscus oscillation like drawing 39 (b), if it thinks that the short oscillation of the period by vibration system B is overlapped on this. The natural period Tc of vibration system A is expressed like a degree type.
[0086]
[Formula 3]

$$T_c = 2\pi\sqrt{\frac{m_2 m_3}{m_2+m_3}\cdot(c_0+c_1)} \qquad (3)$$

[0087] The point that c0 and c1 are parallel connection in vibration system A is characteristic, therefore the natural period Tc of a meniscus oscillation is c (=c0+c1).
It rules "Be alike" over. On the other hand, the natural period TB of vibration system B is expressed like a degree type.
[0088]
[Formula 4]

$$T_B = 2\pi\sqrt{m_0 \cdot c_c} \qquad (4)$$

[0089] cc in a formula 4 is the synthetic acoustic capacitance at the time of carrying out the series connection of the acoustic capacitance c0 of an oscillating element, and the acoustic capacitance c1 of a pressure room, and is expressed with a degree type.
[0090]
[Formula 5]

$$c_c = \frac{1}{\frac{1}{c_0}+\frac{1}{c_1}} \qquad (5)$$

[0091] That is, the point that the synthetic acoustic capacitance cc to which the series connection of c0 and c1 was carried out rules over is the description of vibration system B. This vibration system B differs from the natural frequency of the oscillating element itself seen by the ink jet recording head using the longitudinal-oscillation mold electrostrictive actuator indicated by JP,6-171080,A etc.

Vibration system B is one of the vibration system formed by connecting an oscillating element and a passage system (pressure room) to the last instead of the natural-frequency system of the oscillating element itself.
[0092] As mentioned above, it bends, and in the deforming electrostrictive actuator, since two vibration system exists in a recording head, in order to obtain a normal meniscus oscillation, it is required to control the effect of the above-mentioned vibration system B. It is necessary to fulfill two conditions which make the vibration amplitude of vibration system B small (conditions 1), and make it TB<<Tc (conditions 2) for this implementation. Hereafter, the concrete cure for fulfilling two conditions is described.
[0093] The response of the vibration system B when inputting the step-function-pressure psi can be expressed like a degree type.
[0094]
[Formula 6]

$$u_B(t)=\frac{\psi}{m_0 E_0}\exp(-D_B\cdot t)\sin(E_B\cdot t) \qquad (6)$$

$$\approx\psi\cdot\sqrt{\frac{c_c}{m_0}}\exp(-D_B\cdot t)\sin(E_B\cdot t)$$

$$E_B=\sqrt{\frac{1}{c_c m_0}-D_B^2}$$

$$D_B=\frac{r_0}{2m_0}$$

[0095] That is, since the amplitude of the volume velocity uB produced according to vibration system B is proportional to the 1-/square of cc, in order to make the amplitude of vibration system B small, it needs to set up (conditions 1) and cc small. However, in order to make it not affect the amplitude or natural period of an original meniscus oscillation (vibration system A), it is c (=c0+c1).
** -- it is necessary to minimize cc under certain conditions
[0096] Drawing 11 is a graph which shows the change of cc by the value of c0. In this graph, it calculated as c0+c1=10. This graph shows that what is necessary is just to set c0 and c1 as imbalance (out of balance) with setting out, c0>c1 [i.e.,], or c0<c1, in order to make cc small. However, it needs to be referred to as c0>c1, in order to reconcile the both sides of reservation of the drop volume, and amplitude reduction of vibration system B by that of since the drop volume q decreases as mentioned above if c0 is made small.
[0097] As shown in a degree type, the acoustic capacitance c1 of a pressure room is proportional to the volume W1 of a pressure room. However, kappa is the bulk-modulus [Pa] of ink and alpha is a correction factor (0< alpha<1).
[0098]
[Formula 7]

$$c_1=\frac{W_1}{\kappa\cdot\alpha} \qquad (7)$$

[0099] In the ink jet recording head which carries out the regurgitation of drop volume of 15 or more pls, the minimum of the area of base of a pressure room is about 9x10 to 8 m2, and the minimum of pressure room height is set to about 50 micrometers, in order to secure the fluidity of ink. Therefore, the acoustic capacitance c1 of a pressure room serves as a value more than 2x10-20m5/N. Therefore, in order to control the vibration amplitude of vibration system B small, it is necessary to set up with c0 >=2x10-20m5/N. That is, it is c0 >=2x10-20[m5/N] also from the viewpoint of preventing the effect of vibration system B and obtaining the stable meniscus oscillation.

** -- it becomes important conditions.
[0100] Moreover, in order to reduce the effect vibration system B affects vibration system A, considering as TB<<Tc (conditions 2) is also important. That is, if the natural period TB of vibration system B can be set up sufficiently small compared with Tc, it will become possible to suppress the substantial effect on meniscus behavior small. The natural period TB of vibration system B needs to make cc and m0 small, in order to make TB small, since it is expressed with a formula (4).
[0101] In order to perform fluid simulation and normal expulsion of an ink droplet from the result of a actual regurgitation experiment, it became clear that being referred to as TB<Tc/10 is desirable. Therefore, it is necessary to set up m0 so that the conditions of a bottom type may be satisfied.
[0102]
[Formula 8]

$$m_0 < \frac{1}{c_c}\left(\frac{T_c}{20\pi}\right)^2 = 2.53\times10^{-4}\,\frac{T_c^2}{c_c} \qquad (8)$$

[0103] As stated above, the point which showed clearly that it is what the shimmy of the meniscus shown in drawing 39 (b) depends on the effect of the 2nd vibration system (vibration system B) contained in a head, and clarified further the conditions which can control the adverse effect by vibration system B is also one of the descriptions of this invention. In addition, the example of disclosure which bent and made reference about existence of the above-mentioned vibration system B and its effect in the ink jet recording head using the deforming electrostrictive actuator does not exist, as far as this invention persons get to know.
[0104] As stated so far, from the "large drop regurgitation" and a viewpoint of "normalization (effect control of vibration system B) of a meniscus oscillation", it turned out that c0 is so advantageous that it is large. However, if c0 is enlarged on the other hand as shown in a formula (3), a natural period Tc will increase. As mentioned above, in order to carry out the regurgitation of the minute drop with a meniscus control system, it is necessary to hold down a natural period Tc to below fixed. It is necessary to specifically set Tc as 15 or less microseconds. It is there, next the upper limit of c0 is considered from a viewpoint of setting up a natural period Tc small.
[0105] As shown in a formula (3), Tc is proportional to an m2 and m3/(m2+m3) 1-/square. Inertance m is a parameter decided by duct cross-section A [m2] and duct die-length l [m] like a degree type. However, rho is the consistency [kg/m3] of ink.
[0106]
[Formula 9]

$$m = \frac{\rho l}{A} \qquad (9)$$

[0107] In a general ink jet recording head, the inertance m3 of a nozzle and the inertance m2 of a supply way are set up almost equally. Because, although the refill rate which is an ink supplement rate after the drop regurgitation as it is m3 >>m2 becomes large, regurgitation effectiveness will fall (see the formula 2). On the other hand, although regurgitation effectiveness increases that it is m3 <<m2, a refill rate will fall. Therefore, in a general ink jet recording head, in order to aim at coexistence with regurgitation effectiveness reservation and the increment in a refill rate, it is set up with m2**m3.
[0108] Moreover, if it thinks from the actual nozzle dimensions of 30 micrometers or less of opening, i.e., a diameter, die length of 20 micrometers or more, and the nozzle dimensions used as 15 degrees or less of taper angles, m3 will become a four or more 2x107 kg/m value. therefore, m2 and m3/(m2+m3) -- about -- 1x107 kg/m4 serves as a lower limit.
[0109] Moreover, as mentioned above, as for the acoustic capacitance c1 of a pressure room, abbreviation 2x10-20m5/N serves as a minimum. Therefore, in order to obtain the natural period Tc for 15 or less microseconds from a formula (3), it is necessary to set acoustic capacitance c0 below to 5.5x10-19m5/N. That is, like [natural period / Tc] the case of the drop volume q, although some determinants (parameter) exist, when it is going to set up Tc small, only c0 becomes a rule parameter

substantially. And in order to obtain the natural period Tc for 15 or less microseconds suitable for the globule regurgitation, it becomes a requirement to set acoustic capacitance c0 below to 5.5x10-19m5/N.

[0110] In the ink jet recording head using the electrostrictive actuator which will bend and deform if the above content is summarized, if the drop volume q and a natural period Tc are governed by the acoustic capacitance c0 of an oscillating element and the upper limit/lower limit of other parameters are taken into consideration, the optimal range exists in c0. That is, the "large drop regurgitation" and the "globule regurgitation" can be reconciled by setting up acoustic capacitance c0 so that the conditions of a degree type may be satisfied.

2.0x10-20 <=c0 <=5.5x10-19 [m5/N] (10)

[0111] Moreover, by satisfying the conditions of c0>c1 and a formula (8), the effect of the 2nd vibration system (vibration system B) formed in a head can be controlled, and the ink jet recording head excellent in regurgitation stability and dependability can be realized. Furthermore, by setting the aspect ratio of a pressure room as abbreviation 1, c0 per unit area can be maximized and an ink jet recording head with a high nozzle consistency can be realized.

[0112] With reference to a drawing, this invention is further explained to a detail based on the example of the 1st operation gestalt concerning this invention below the example of the 1st operation gestalt. The concrete configuration of the oscillating element which fills the conditions of c>=2.0x10-20m5/N with this example of an operation gestalt is investigated and made as an experiment, and it is shown as a result of having conducted the expulsion-of-an-ink-droplet experiment. Drawing 12 is a perspective view shown where the ink jet recording head of this example of an operation gestalt is developed.

[0113] The diaphragm 41 with which this ink jet recording head accomplishes a part of the ink pool plate 38, ink umbilical plate 39, pressure room plate 40 with which two or more pressure rooms 14 were formed, and wall surface of the pressure room 14 at the nozzle plate 29 top by which two or more nozzles 13 were formed in the shape of a matrix (letter of a matrix) is joined to this order. Two or more electrostrictive actuators 16 are joined to the diaphragm 41 so that each pressure room 14 may be countered.

[0114] Drawing 13 is a top view shown where a part of configuration of drawing 12 is seen through. The nozzle configuration of this example of an operation gestalt is considered as the array of the shape of a matrix of eight line x8 train. The nozzle pitch in a line writing direction is 42.3 micrometers corresponding to resolution 600dpi. Therefore, a row pitch is 42.3micrometerx8 train =338micrometer, and width of face in the line writing direction of the pressure room 14 is set to 328 micrometers settled in the pitch.

[0115] Moreover, a row pitch is also set to 338 micrometers and width of face in the direction of a train of the pressure room 14 is set to 328 micrometers settled in the pitch. That is, the flat-surface configuration of the pressure room 14 is a square. The flat-surface configuration of an oscillating element is also the same as the flat-surface configuration of the pressure room 14, and, as for the plane area, area is made small 0.108mm more nearly substantially than 2 and the conventional structure. When the flat-surface dimension of an oscillating element is decided, the structure parameter which determines acoustic capacitance is only the diaphragm 41, the construction material of an electrostrictive actuator 16, and thickness which are the configuration member. Here, the construction material of stainless steel (SUS304) and an electrostrictive actuator 16 was decided to be titanic-acid lead zirconate system ceramics for the construction material of a diaphragm 41. Therefore, the structure parameter which remains is the thickness of these two members.

[0116] In order to decide thickness, the relation between the thickness of two members and acoustic capacitance c0 was investigated first. For calculation of acoustic capacitance c0, excluded volume deltaV at the time of impressing the homogeneity pressure p to the structure-model-ized oscillating element using finite element analysis was calculated, and it considered as c0=deltaV/p.

[0117] What summarized the above-mentioned result is shown in the graph of drawing 14 . In a graph, the thickness of a diaphragm 41 is taken along an axis of abscissa, the thickness of an electrostrictive actuator 16 is taken along an axis of ordinate, analysis examination of the acoustic capacitance c0 to those combination is conducted, and it is c0 >=2.0x10-20[m5/N].

The field of the combination with which ****** is filled was smeared away and expressed. In every thickness combination in the field, the excluded volume of an oscillating element can obtain 15 or more pls. Therefore, in the ink jet recording head using this, the regurgitation of the ink droplet of 15 or more pls can be carried out.
[0118] In this example of an operation gestalt, the prototype which set thickness of 5 micrometers and an electrostrictive actuator 16 to 10 micrometers for the thickness of a diaphragm 41 was performed as one of the solution of the, and the expulsion-of-an-ink-droplet experiment was further conducted combining ink passage. The example is shown below.
[0119] That is, the whole of the dimension of a nozzle plate 29, the ink pool plate 38, the supply way plate 39, the pressure room plate 40, and a diaphragm 41 is the same, and width of face in the direction in which 4mm, a head scanning direction, and the width of face in a head scanning direction cross at right angles is set to 4mm. Moreover, also let all construction material be stainless steel (SUS304).
[0120] By press working of sheet metal, thickness is 50 micrometers, and a nozzle plate 29 follows an above-mentioned layout, and is penetrated, and the nozzle 13 of the shape of a matrix with a diameter of 25 micrometers is formed. The thickness of the ink pool plate 38 is 200 micrometers, with a diameter of 28 micrometers which is open for free passage for nozzle 13 free passage hole 38a is formed by press working of sheet metal, and ink pool 38b is formed by etching processing.
[0121] With a diameter of 25 micrometers to which thickness opens supply way plate 39 for free passage to with a diameter of 28 micrometers which is 50 micrometers and is open for free passage for nozzle 13 with press working of sheet metal free passage hole 39a, and ink pool 38b ink supply way 39b is formed. Thickness is 80 micrometers, according to the above-mentioned flat-surface configuration, it is etching processing and, as for the pressure room plate 40, two or more pressure rooms 14 are formed. As already stated, thickness is set to 5 micrometers, and a diaphragm 41 has conductivity, and functions also as a common electrode for impressing the driver voltage wave of an electrostrictive actuator 16. The alignment marker (not shown) for carrying out positioning junction is mutually given to five kinds of above plates.
[0122] Thickness is set to 10 micrometers as the electrostrictive actuator 16 was already described. Each electrostrictive actuator 16 is formed according to the individual on the diaphragm 41 corresponding to each pressure room 14, and that of the flat-surface configuration is the same as that of the appearance of the pressure room 14.
[0123] The electrode layer is formed in both sides of an electrostrictive actuator 16, respectively. The flexible cable (not shown) which has an electric circuit pattern, and the electrode layer by the side of the free surface of an electrostrictive actuator 16 (individual electrode) are electrically connected through wirebonding.
[0124] Next, the manufacture approach of the ink jet recording head of this example of an operation gestalt is explained. Drawing 15 is the perspective view showing this manufacture approach, and (a) - (d) shows each process gradually. First, as shown in drawing 15 (a), lap polish processing is performed to a cylinder-like block [piezoelectric-material] (not shown), and the piezoelectric-material plate 42 is produced. Polish processing is performed so that thickness may become the same as the design thickness of an electrostrictive actuator 16. An electrode layer 43 is formed in both sides of this piezoelectric-material plate 42 by sputtering, respectively. In this example of an operation gestalt, gold (Au) was used as an electrode material of an electrode layer 43.
[0125] Subsequently, as shown in drawing 15 (b), temporary immobilization of the piezoelectric-material plate [finishing / sputtering] 42 is carried out at a stationary plate 45 through the adhesion foaming tape 44 which has the property whose adhesion is lost at the time of an elevated temperature. The alignment marker (not shown) for performing junction positioning with a nozzle plate 29, the pressure room plate 40, and the SUS plate of diaphragm 41 grade is prepared in this stationary plate 45.
[0126] Furthermore, as shown in drawing 15 (c), the film mask 46 which has photosensitivity is stuck on the piezoelectric-material plate 42 which carried out temporary immobilization. In this example of an operation gestalt, the urethane system film mask with a thickness of 10 micrometers is used as a film mask 46. Then, the exposure mask 47 formed in the pattern which makes only the part which it leaves as

an electrostrictive actuator 16 penetrate ultraviolet rays (UV) is prepared separately. Patterning of this film mask 46 is carried out on the basis of the alignment marker of a stationary plate 45.
[0127] Then, UV exposure is performed on the piezoelectric-material plate 42 covered with the film mask 46 using the exposure mask 47, and it etches into the film mask 46 further. What has the property that the part to which the UV irradiation of the film mask 46 was carried out is not removed, but the other part can be removed certainly is chosen as an etching reagent. The sodium-carbonate solution was used in this example of an operation gestalt.
[0128] The film mask 46 is covered with the process to the above only into a part to leave as an electrostrictive actuator 16, and the film mask 46 is removed from the other part. Then, sandblasting processing is performed to this structure. This sandblasting processing is performed under conditions which carry out grinding clearance of the piezoelectric-material plate 42 of a part which the film mask 46 was removed and was exposed certainly, and do not carry out grinding of the part in which the film mask 46 remained.
[0129] Then, the film mask 46 which remained on the front face of the piezoelectric-material plate 42 is removed and washed. According to the above process, as shown in drawing 15 (d), both sides can be equipped with an electrode layer 31, and the piezoelectric material of the structure which stuck the wafer-ized electrostrictive actuator 16 on the adhesion foaming tape 44 on the stationary plate 45 can be obtained.
[0130] Subsequently, the process which sticks the above-mentioned piezoelectric material on a diaphragm 41 is performed. First, adhesives (not shown) are applied to the front face of the piezoelectric material shown in drawing 15 (d). In this example of an operation gestalt, since a diaphragm 41 is made to serve a double purpose as a common electrode, the adhesives which have conductivity are used for the adhesives to apply. After applying this, superposition and 2kg [per square centimeter] application of pressure are performed for piezoelectric material and a diaphragm 41 by making the alignment marker of a diaphragm 41 and a stationary plate 45 into positioning criteria, adhesives thermosetting in the bottom of the temperature of 200 degrees C are stiffened, and both sides are joined. In addition, since the adhesion foaming tape 44 used in order to carry out temporary immobilization of piezoelectric material and the stationary plate 45 at the time of this heating loses adhesion with heat, it exfoliates easily.
[0131] According to the above process, it has the electrostrictive actuator 16 wafer-ized on Perilla frutescens (L.) Britton var. crispa (Thunb.) Decne. as the common electrode in the diaphragm 41, and the unit with which the individual electrode was prepared on each electrostrictive actuator 16 is obtained. This unit is pasted up and joined with the plate unit which is the junction article of nozzle plates 29 other than diaphragm 41 joined [which joined and positioning-pasted up] separately, the ink pool plate 38, the supply way plate 39, and the pressure room plate 40. Thereby, an ink jet recording head can be obtained.
[0132] Finally, electrical connection for impressing a driver voltage wave to each electrostrictive actuator 16 is performed. In this example of an operation gestalt, the FPC cable (not shown) was stuck on the periphery of an ink jet recording head, and the electrode terminal and individual electrode of each electrostrictive actuator 16 were connected by wirebonding.
[0133] Next, actuation of this example of an operation gestalt is explained. That is, each pressure room 14 is filled up with ink via ink pool 38b to ink supply way 39b shown in drawing 12 to the ink jet recording head made as an experiment as mentioned above. Then, if driver voltage is impressed between the individual electrode of each electrostrictive actuator 16, and a diaphragm 41 (common electrode), the oscillating element which consists of a diaphragm 41 and an electrostrictive actuator 16 will bend, it will deform, and an ink droplet will carry out the regurgitation from the corresponding nozzle 13 by compressing the ink with which it filled up in the pressure room 14.
[0134] The regurgitation experiment of an ink droplet was conducted using the above ink jet recording head. Drawing 16 is a graph which shows the driver voltage wave used in this experiment. In the graph, an electrical potential difference [V] is taken along an axis of ordinate, and time amount [mus] is taken along the axis of abscissa.

[0135] First, the driver voltage wave shown in drawing 16 is inputted into each oscillating element according to an individual. Consequently, it checked that the ink droplet of 20pl(s) stabilized and carried out the regurgitation from each nozzle 13. Furthermore, the number of the oscillating elements driven simultaneously was changed, and the same experiment was conducted. Consequently, it checked that it was stabilized and the regurgitation of the ink droplet of the same drop measure could be carried out irrespective of the number to drive. Moreover, the difference in the regurgitation property (whenever [regurgitation drop volume and regurgitation drop speed], discharge direction) by the location to drive was not checked, either.
[0136] In the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.2x10-20m5/N by structural analysis and location survey assessment by the finite element method. That is, the ink jet recording head of this example of an operation gestalt is c0 >=2.0x10-20[m5/N].
****** is filled.
[0137] that is, the thing which the large drop regurgitation of 15 or more pls will become possible if the conditions of c0 >=2.0x10-20m5/N are fulfilled -- the experimental result of this example of an operation gestalt -- it was checked.
[0138] Example drawing 17 of the 2nd operation gestalt is the perspective view which developed the ink jet recording head of this example of an operation gestalt. In this ink jet recording head, ink passage is formed by carrying out laminating junction of a total of a nozzle plate 1, the common passage plate 2, the supply way plate 4, the pressure room plate 5, and the five plates of a diaphragm 6 with adhesives.
[0139] Common passage is constituted by one mainstream way 7 and 26 branching passage (five are displayed in drawing 17) 8. The mainstream way 7 is open for free passage on the ink tank (not shown) through a feed hopper 9, and has the function which supplies ink to each branching passage. Every ten pressure rooms 14 are connected with each branching passage 8, respectively (five pieces are displayed in drawing 17). That is, the ink jet recording head of this example of an operation gestalt is constituted as a matrix-like array head which has 260 ejectors.
[0140] Drawing 18 is drawing having shown the cross section of one ejector. The pressure room 12 is connected with the branching passage 8 through the ink feed holes 11, and it fills up with ink in the pressure room 12. The nozzle 10 for carrying out the regurgitation of the ink droplet is connected with each pressure room 12. Moreover, the diaphragm 6 is formed in the base of the pressure room 12, and the electrostrictive actuator 27 is attached in the diaphragm 6. When a driver voltage wave is impressed to this electrostrictive actuator 27, an electrostrictive actuator 27 bends and deforms and makes the pressure room 12 expand or compress. If a volume change arises in the pressure room 12, a pressure wave will occur in the pressure room 12. The ink of the nozzle section exercises, it is discharged by operation of this pressure wave from a nozzle 10 outside, and an ink droplet is formed of it. In addition, 24 shows a free passage way.
[0141] In this example of an operation gestalt, the polyimide film with a thickness of 25 micrometers was used for the nozzle plate 1, and the nozzle 10 of 25 micrometers of diameters of opening was formed by excimer laser processing. If a resin film is used for the member (nozzle plate 1) which forms a nozzle like this example of an operation gestalt, a nozzle plate 1 can be operated as an air damper of the branching passage 8, and the regurgitation stability at the time of the multi-nozzle simultaneous regurgitation can be raised. That is, in head structure as shown in drawing 18 , if the nozzle plate in which a nozzle 10 is formed is formed with a resin film, a part of wall surface (top face) of the branching passage 8 will serve as a resin film. If the wall surface of branching passage is constituted from a rigid low resin film, the acoustic capacitance of branching passage can increase substantially, generating of the sound wave propagation (cross talk) through branching passage etc. can be prevented, and the regurgitation stability at the time of the multi-nozzle simultaneous regurgitation can be raised. In addition, in order to secure sufficient acoustic capacitance for branching passage and to give the functions (cellular contamination prevention on a discharge direction disposition etc.) as a nozzle to the nozzle section, it is suitable for the thickness of a resin film that it is within the limits of 20-70 micrometers. However, even if it is except this optimum range, it is possible to acquire the same

operation effectiveness with imperfection. The ink feed holes 11 of 26 micrometers of diameters of opening were formed in the supply way plate 4 with a press using the stainless plate with a thickness of 75 micrometers.
[0142] The passage pattern was formed in the common passage plate 2 and the pressure room plate 5 by wet etching using the stainless plate with a thickness of 100 micrometers. Die length of one side used the pressure room 12 as the square of 500 micrometers and an aspect ratio 1, and as shown in drawing 19 (a), in order to prevent the stagnation of ink flow, it gave R configuration to the corner of the pressure room 12. The stainless plate (Ev=197GPa) with a thickness of 10 micrometers was used for the diaphragm 6. Px in drawing 19 (a) shows the nozzle pitch of a main scanning direction 428 (refer to drawing 42), and Py shows the nozzle pitch of the direction 429 of vertical scanning, respectively.
[0143] Drawing 19 (b) is drawing having shown the configuration of the electrostrictive actuator 27 used in this example of an operation gestalt. Veneer-like piezo-electricity ceramics (titanic-acid lead zirconate system ceramics) (Ep=200GPa) with a thickness of 30 micrometers was used for the electrostrictive actuator 27. Width of face Wp of an electrostrictive actuator was set to 490 micrometers almost equal to the pressure room width of face W, and used the sandblasting processing method for processing. In addition, 37 shows the electrode pad section and 38 shows an actuator, respectively.
[0144] As a result of structural analysis and location survey assessment by the finite element method, by the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.2x10-20m5/N, and the inertance m0 was called for with 1.3x106 kg/m4. Moreover, the acoustic capacitance of the pressure room 12 was 2.0x10-20m5/N (cc=1.2x10-20m5/N). That is, the ink jet recording head of this example of an operation gestalt fulfills the conditions of a formula (8) and a formula (10).
[0145] The driver voltage wave used for drawing 40 in this example of an operation gestalt is shown. drawing 40 -- (-- c --) -- being shown -- a large -- a drop -- ** -- driver voltage -- a wave -- comparatively -- being loose -- starting -- time amount -- a pressure -- a room -- compressing -- a sake -- the -- one -- an electrical potential difference -- change -- a process -- 402 -- " -- and -- fixed -- a period -- an electrical potential difference -- having held -- after -- applied voltage -- reference voltage (offset voltage Vb) -- returning -- a sake -- the -- two -- an electrical potential difference -- change -- a process -- 404 -- " -- constituting -- having -- **** . If this driver voltage wave is impressed to an electrostrictive actuator, a big pressure will occur in the pressure interior of a room to the timing to which 1st electrical-potential-difference change process 402" was impressed, and the ink in a nozzle will be injected towards the recording paper. It was set as section t7 "=15microsecond and electrical-potential-difference variation V2" =30V and bias voltage Vb=20V section t3 "=5microsecond and section t4" =10microsecond, respectively.
[0146] On the other hand, the driver voltage wave for globules shown in drawing 40 (a) is constituted by the 4th electrical-potential-difference change process 404 for returning the 3rd electrical-potential-difference change process 403 for expanding the 2nd electrical-potential-difference change process 402 for compressing the 1st electrical-potential-difference change process 401 for expanding a pressure room just before the regurgitation, and a pressure room at a rapid rate, and a pressure room at a rapid rate, and applied voltage to reference voltage. If this driver voltage wave is impressed to an electrostrictive actuator, the meniscus of nozzle opening will once be drawn in a pressure generating room side by the 1st electrical-potential-difference change process 401, and will form the meniscus of a concave configuration according to it.
[0147] Then, if the 2nd electrical-potential-difference change process 402 is added, a thin liquid column will be formed in a nozzle center section, and when a liquid column is further divided at an early stage by the 3rd electrical-potential-difference change process 403, an ink droplet smaller than the diameter of a nozzle will be breathed out. That is, this driver voltage wave is an actuation wave for carrying out the regurgitation of the minute drop with a meniscus control system. It was set as electrical-potential-difference variation V1=15V, electrical-potential-difference variation V2=12V, electrical-potential-difference variation V3=17V, and bias voltage Vb=20V, respectively section t1=2microsecond, section t2=2microsecond, section t3=2microsecond, section t4=0.5microsecond, section t5=2microsecond,

section t6=5microsecond, and section t7=15microsecond.
[0148] drawing 40 -- (-- b --) -- being shown -- inside -- a drop -- ** -- driver voltage -- a wave -- a globule -- the same -- a meniscus -- control -- having used -- a thing -- it is -- the regurgitation -- just before -- a pressure -- a room -- expanding -- making -- a sake -- the -- one -- an electrical potential difference -- change -- a process -- 401 -- ' -- a pressure -- a room -- being rapid -- a rate -- compressing -- a sake -- the -- two -- an electrical potential difference -- change -- a process -- 402 -- ' -- and -- applied voltage -- reference voltage -- returning -- a sake -- the -- three -- an electrical potential difference -- change -- a process -- 404 -- ' -- constituting -- having -- **** -- . Like the 3rd electrical-potential-difference change process 403 of the driver voltage wave for globules, in early fragmentation of a liquid column, in order to hold a fixed period electrical potential difference after ******** and 2nd electrical-potential-difference change process 402', a bigger ink droplet a little than a globule is breathed out. It was set as electrical-potential-difference variation V1'=15V, electrical-potential-difference variation V2'=20V, and bias voltage Vb=20V, respectively section t1'=2microsecond, section t2'=2microsecond, section t3'=2microsecond, section t4'=10microsecond, and section t7=15microsecond.
[0149] In addition, the actuation wave shown in drawing 40 is an example which shows the actuation approach of the ink jet recording head of this invention, and can also use the actuation wave of other configurations. That is, as long as it includes at least the 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which shrinks the volume of a pressure room as a wave for large drop regurgitation, and making an ink droplet breathing out, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room, the actuation wave of a different configuration from drawing 40 (c) may be used.
[0150] For example, the electrical-potential-difference change process for drawing a meniscus in the interior of a nozzle slightly may be added just before 1st electrical-potential-difference change process 402", or another electrical-potential-difference change process may be added after 2nd electrical-potential-difference change process 404." As long as it includes at least the 1st electrical-potential-difference change process of similarly impressing an electrical potential difference in the direction which expands the volume of said pressure room as a wave for globule regurgitation, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which compresses the volume of said pressure room, the actuation wave of a different configuration from drawing 40 (a) may be used. For example, it may consider as the actuation wave which does not have the 3rd electrical-potential-difference change process 403 and the 4th electrical-potential-difference change process 404, or another electrical-potential-difference change process for controlling the initial state of a meniscus may be added just before the 1st electrical-potential-difference change process 401.
[0151] Drawing 41 is drawing having shown the basic configuration of the actuation circuit used in this example of an operation gestalt. In case image recording by the drop diameter modulation technique is performed, it impresses changing the driver voltage wave shown in drawing 40 for every pressure room to the electrostrictive actuator corresponding to each pressure room, and the drop diameter of the ink droplet made to breathe out is changed. In this example of an operation gestalt, in order to generate three sorts of driver voltage waves shown in drawing 40 (a) - (c), it has three kinds of wave generating circuits 411, 411', and 411", and each wave is amplified by an amplifying circuit 412, 412', and 412." Based on image data, at the time of record, an electrostrictive actuator 414, 414', and the driver voltage wave impressed to 414" are changed by a switching circuit 413, 413', and 413", and the ink droplet of a request drop diameter is breathed out at it.
[0152] The regurgitation experiment of an ink droplet was conducted using the ink jet recording head of this example of an operation gestalt described above. As a result of impressing the actuation wave (V1"=30V) shown in drawing 40 (c) to an electrostrictive actuator 27, it was checked that the ink droplet of drop volume 20pl is stabilized, and is breathed out from each nozzle 10. That is, it has checked experimentally that the regurgitation of the large drop exceeding 15pl becomes possible by using the electrostrictive actuator 27 which fulfills the conditions of acoustic capacitance c0 >=2.0x10-20m5/N.

Moreover, refill time amount was also as brief as about 40 microseconds, and 18kHz high-speed actuation was possible for it.
[0153] As a result of performing image recording in the record paper using the ink jet recording head of this example of an operation gestalt, image concentration (OD value 1.3) sufficient also in the low record resolution of 600dpi was able to be obtained. That is, in the ink jet recording head of this example of an operation gestalt, since the large drop regurgitation of drop volume 20pl is possible, image concentration sufficient also in low record resolution called 600dpi can be obtained, and it can be said that it is an ink jet recording head very advantageous to high-speed record. In addition, when the applied voltage of an actuation wave was made to increase to V1"=40V, the drop volume of 27pl was obtained and image concentration (OD value 1.2) sufficient also in the record resolution of 300dpi was able to be obtained.
[0154] Drawing 21 is the result of observing a meniscus oscillation of the ink jet recording head of this example of an operation gestalt with a laser-doppler meter. It was checked that the natural period Tc of a pressure wave is small stopped with 9.5 microseconds. That is, the natural period Tc for 15 or less microseconds suitable for the minute drop regurgitation was able to be obtained by using the oscillating element which fulfills the conditions of acoustic capacitance c0 <=5.5x10-19m5/N.
[0155] Moreover, in the ink jet recording head of this example of an operation gestalt, a fine oscillation was not able to be overlapped on a meniscus oscillation, but the very good meniscus oscillation was able to be obtained so that the meniscus oscillating wave of drawing 21 might show. The ink jet recording head of this example of an operation gestalt fulfills a formula (8) and the conditions of c0>c1, and this is because the amplitude of the vibration system B mentioned above is stopped small. Since such a stable oscillation was obtained by the meniscus, very high regurgitation stability was able to be acquired in the ink jet recording head of this example of an operation gestalt.
[0156] Moreover, when the globule regurgitation was performed by the actuation wave shown in drawing 40 (a), it was checked that the regurgitation of the minute ink droplet of drop volume 2pl can be carried out to stability. That is, in the ink jet recording head of this example of an operation gestalt, the natural period was as short as 9.5 microseconds, and since the shimmy of a meniscus was controlled, the minute drop regurgitation by the meniscus control system was able to be performed good. That is, in the ink jet recording head of this example of an operation gestalt, drop diameter modulation record was able to be performed in the large drop diameter range of 2-20pl by being impressed by each electrostrictive actuator, coexistence with the "large drop regurgitation" and the "globule regurgitation" being possible, and changing the driver voltage wave shown in drawing 40 according to an image pattern.
[0157] As an example of a comparison, thickness tp of an electrostrictive actuator, the thickness tv of a diaphragm, and the pressure room width of face W were changed, and same characterization was carried out. Consequently, as O plot of drawing 6 showed the drop volume, the structural-analysis result and the result which is in agreement with fitness were obtained. That is, although drop volume of 15 or more pls was obtained in the range of c0 >=2.0x10-20m5/N, on condition that c0<2.0x10-20m5/N, only drop volume of less than 15 pls was obtained, and sufficient image concentration was not able to be obtained. In addition, the conditions used as c0<2.0x10-20m5/N are combination, such as W= 500 micrometers, tv=10micrometer, tp=45micrometer, W= 400 micrometers, tv=5micrometer, and tp=35micrometer.
[0158] Although drop volume of 15 or more pls was obtained, the natural period Tc was set to 15 microseconds or more, and it became impossible moreover, to perform the globule regurgitation of 4 or less pls, when set to c0>5.5x10-19m5/N. The conditions used as c0>5.5x10-19m5/N are combination, such as W= 700 micrometers, tv=10micrometer, tp=15micrometer, W= 1000 micrometers, tv=10micrometer, and tp=35micrometer.
[0159] That a formula (10) is appropriate has checked experimentally as conditions for securing drop volume of 15 or more pls, and obtaining the natural period Tc for 15 or less microseconds from the above result. In addition, when an aspect ratio uses the pressure room of abbreviation 1, in order to set the acoustic capacitance of an oscillating element as the range of 2.0x10-20 <=c0 <=5.5x10-19 m5/N, it is desirable to set the thickness of 300-700 micrometers (plane area 0.09-0.5mm2), a diaphragm, and an electrostrictive actuator as the range of 5-20 micrometers and 15-40 micrometers for pressure room

width of face, respectively.
[0160] Moreover, prototype assessment of a head was performed also about the rectangular pressure room whose aspect ratio is not abbreviation 1. Consequently, also at the rectangular pressure room, when fulfilling the conditions of a formula (10), it has checked that drop volume of 15 or more pls and the natural period for 15 or less microseconds were securable. However, although the same drop volume is obtained, one (the area of base of a pressure room) 2 to 5 times the actuation area of this is needed.
[0161] For example, in order to obtain the same drop volume (20pl) as the ink jet recording head of this example of an operation gestalt, in the ink jet recording head of an aspect ratio 5, 300x1500 micrometers of pressure room sizes needed to be set to 2. This is a twice [about] as many pressure room area as this as compared with the ink jet recording head of this example of an operation gestalt, therefore it means the array consistency of a nozzle falling to one half. That is, when fulfilling the conditions of a formula (10) also at the pressure room of a rectangle configuration, the target property was acquired, but in order to make it compatible with a high nozzle consistency, it was confirmed that it is optimal to set the aspect ratio of a pressure room as abbreviation 1.
[0162] In addition, although the flat-surface configuration of an oscillating element can be made into an abbreviation equilateral triangle, an abbreviation square, or an approximate regular hexagon in the ink jet recording head of this example of an operation gestalt as mentioned above, as for these oscillating element, it is desirable to form a part for the joint of two sides each which adjoins mutually in the shape of a curve. That is, R configuration can be given to the corner (corner) of the pressure room 12 as shown in drawing 19 (a). This is for preventing that the stagnation point of ink occurs in the pressure interior of a room, and raising eccritic [of air bubbles].
[0163] That is, although the pressure wave which the pressure interior of a room was made to generate performs the regurgitation of an ink droplet in an ink jet recording head, if air bubbles remain in the pressure interior of a room, pressure generating effectiveness will fall, and the volume and drop speed of an ink droplet will decrease. The drop regurgitation may become impossible if residual air bubbles are large. So, in the usual ink jet recording device, cellular clearance of the pressure interior of a room is performed by attracting ink from a nozzle. However, since the stagnation point (part with the slow rate of flow) of ink occurs in the pressure interior of a room when the aspect ratio of a pressure room exists in 1 and an angle exists in near and a pressure room, cellular blowdown becomes difficult.
[0164] So, in the ink jet recording head of this example of an operation gestalt, by giving R configuration to the corner of a pressure room, generating of a stagnation point was prevented and it raised cellular eccritic one. as a result of investigate the cellular survival rate of the pressure interior of a room after actually perform ink attraction on certain conditions (ink be attract for 5 seconds by the pressure of 200mmHg(s) from a nozzle), when R configuration be gave, by the ink jet recording head of this example of an operation gestalt which added R configuration (curvilinear configuration), cellular survival be checked to the cellular survival rate having be 0 at 15 % of pressure room.
[0165] In the ink jet recording head of this example of an operation gestalt, since the high density array of many pressure rooms and electrostrictive actuators is carried out at the shape of a matrix, it becomes very difficult to perform electrical connection to each electrostrictive actuator. That is, as shown in drawing 35 , when the pressure room is arranged in one dimension, or when the high density array of many pressure rooms is carried out two-dimensional like this example of an operation gestalt although it is possible like the example of the 1st operation gestalt to perform electrical connection easily by the conventional electrical connection approaches (wirebonding etc.) when the number of pressure rooms also has little two-dimensional array, it is impossible to apply the conventional electrical connection approach.
[0166] So, in this example of an operation gestalt, the electrical connection approach as shown in drawing 22 and drawing 23 was used. That is, as the electrode pad section 37 (refer to drawing 19 (b)) was formed in an electrostrictive actuator and it was shown in drawing 22 , the electrical potential difference was impressed to each electrostrictive actuator by carrying out electrical connection of this electrode pad section and the wiring substrate (FPC substrate) 311 through a solder bump. Hereafter, it explains in more detail about the electrical connection approach of this example of an operation gestalt.

[0167] Drawing 22 (a) and (b) are the sectional view where the perspective view of before electric junction / back, drawing 23 (a), and (b) met the A-A line of drawing 22 (a), respectively, and the sectional view which met the B-B line of drawing 22 (b). The electrode 321 for common signals and the electrode 322 for individual signals are formed in the 2nd page which the electrostrictive actuator 312 arranged in the shape of a matrix counters, respectively, and the electrode 321 for common signals is joined to the conductive diaphragm 313 electrically and mechanically. The electrode 321 for common signals made the two-layer structure of Cr (0.2 micrometers) and Au (0.2 micrometers), and the electrode 322 for individual signals three layer systems of Cr (0.2 micrometers), and nickel (0.6 micrometers) and Au (0.2 micrometers).
[0168] The flexible-printed-wiring substrate (FPC substrate) 311 with which the individual signal line (signal line) was formed consists of three layers, the base film 323 which consists of resin material, the circuit pattern 324 which consists of a metallic conductor, and the covering layer 325. Moreover, the electrode 327 for individual signals is formed in the electrode pad section 326 of an electrostrictive actuator, and a corresponding location, and the bump 330 of the shape of a semi-sphere which consists of conductive core material 328 and conductive jointing materials for corrugated fibreboard 329 is formed on this electrode 327. In this example of an operation gestalt, using Cu as core material 328, the pewter was formed in the front face of the core material 328 as a jointing material for corrugated fibreboard with electrolysis plating, and the bump was produced. At this example of an operation gestalt, it is phi150micrometer about a bump's path. Height was set as 60 micrometers.
[0169] At the time of electric junction, the FPC substrate 311 and an electrostrictive actuator 312 are made to counter mutually, where alignment is taken, application of pressure and heating are performed so that the location of the electrode pad section and a bump may be in agreement, and a bump 330 is joined for a jointing material for corrugated fibreboard to an electrode pad electrically and mechanically melting and by making it flow on an electrode pad. The pad 327 for electric junction on a diaphragm 313 and the FPC substrate 311 is electrically joined to the control circuit (not shown), and driver voltage is impressed to an electrostrictive actuator 312 through an individual signal line.
[0170] In the ink jet recording head of this example of an operation gestalt, the bump 330 is formed in the shape of a semi-sphere. This is for making the contact condition of the electrode pad section and a bump into homogeneity certainly. That is, even when gap arises in the parallelism of the FPC substrate 311 and an electrostrictive actuator 312, by what the bump is made hemispherical for, the contact condition of the electrode pad section and a bump 330 can be equalized, and while the stable electrical connection becomes possible, destruction of the electrostrictive actuator 312 at the time of electrical connection can be prevented.
[0171] Moreover, although the high FPC substrate 311 of flexibility is used for the wiring substrate in the ink jet recording head of this example of an operation gestalt, it is for this also securing positive contact between the electrode pad section and a bump 330. That is, if a wiring substrate is constituted from a low rigid-body ingredient of flexibility, it will be easy to generate poor contact between the electrode pad section and a bump 330 by the curvature of the passage plate to which the electrostrictive actuator was joined, or the variation of the thickness of an electrostrictive actuator selectively. On the other hand, if a wiring substrate is constituted from a high ingredient of flexibility, according to deformation of a wiring substrate, above-mentioned curvature and above-mentioned thickness dispersion can be absorbed, and uniform contact can be secured in all electrical connection parts.
[0172] Moreover, when the high ingredient of flexibility was used for the wiring substrate and an electrostrictive actuator 312 is driven, the stress generated between a bump 330 and the wiring substrate 311 can be reduced. That is, if an electrostrictive actuator 312 is driven, in order to also displace some electrode pad sections, the bump 330 on the electrode pad section also displaces together. If the rigid high substrate is used for the wiring substrate at this time, big stress will occur between each of the electrode pad section, a bump, and a wiring substrate, and producing fracture of an electrical connection etc. will become the cause of reducing the dependability of an electrical connection greatly. On the other hand, if the high ingredient of flexibility is used for a wiring substrate like this example of an operation gestalt, since a wiring substrate can be deformed according to a bump's variation rate, generating of

stress can be controlled and it becomes possible to realize a reliable ink jet recording head.
[0173] Furthermore, the core material 328 is inserted in the interior of a bump 440 in the ink jet recording head of this example of an operation gestalt. Since it becomes possible to form a gap between an electrostrictive actuator 312 and the FPC substrate 311 after electrical connection by this, it becomes possible to bend freely and to deform, without an electrostrictive actuator 312 being restrained by the FPC substrate. That is, the poor property of the electrostrictive actuator 312 resulting from contact to an electrostrictive actuator 312 and the wiring substrate 311 can be prevented, and it becomes possible to realize a reliable ink jet recording head. Moreover, if a gap exists between an electrostrictive actuator 312 and the FPC substrate 311, it will become possible an air cooling without blower or to carry out forced-air cooling about the heat generated by actuation of an electrostrictive actuator 312, and it will also become possible to control change of the electrostrictive actuator property by the temperature rise.
[0174] By using the above electrical connection approaches, positive electrical connection can be made possible also to the electrostrictive actuator 312 by which the high density array was carried out two-dimensional. That is, since the wiring substrate 311 is arranged above an electrostrictive actuator 312, the tooth space which arranges a signal line can be secured to the maximum, and it becomes possible to set up the array consistency of a nozzle highly as a result.
[0175] For example, since it is easy to form the circuit pattern of 50-micrometer pitch on the FPC substrate 311 when size arranges 500x500 micrometers of electrostrictive actuators 312 of 2 in the shape of a matrix by 10x10, the array pitch of an electrostrictive actuator 312 can be small set up to 575-micrometer pitch. This is a numeric value unrealizable by the conventional electrical connection approach in a matrix-like array head as shown in drawing 24 (a) and (b).
[0176] For example, with the conventional electrical connection technique which forms the individual signal line 335 in the same flat surface as an electrostrictive actuator 331, as shown in drawing 24 (b), since the minimum wiring pitch by screen-stencil is generally about 0.3mm, as for the array pitch of an electrostrictive actuator 331, about 3.6mm becomes a minimum. That is, the electrical connection approach like this example of an operation gestalt can be said to be a very effective approach when raising the nozzle consistency in a matrix-like array head. 333 in drawing and 336 show the wiring substrate, respectively.
[0177] Example drawing 25 of the 3rd operation gestalt (a) is the top view showing the head structure of this example of an operation gestalt. The ink jet recording head of this example of an operation gestalt has the description at the point of having set up smaller than the width of face W of the pressure room 242 the width of face Wp of an electrostrictive actuator 241, although basic structure is almost the same as the example of the 1st operation gestalt. That is, in case an electrostrictive actuator is joined on a diaphragm by setting up smaller than the pressure room width of face W the width of face Wp of an electrostrictive actuator 241, even if a location gap occurs, the acoustic capacitance c0 of an oscillating element can prevent changing sharply, and becomes possible [suppressing change of the drop volume and a natural period to min].
[0178] Drawing 26 is the result of investigating the change of which occurs in acoustic capacitance c0 with the width of face Wp of an electrostrictive actuator 241, when a center position gap of the pressure room 242 and the actuator 243 (part which bends actually and deforms) of an electrostrictive actuator 241 is set to delta [mum]. From this result, when setting up Wp so that the following conditions (formula (11)) might be satisfied, it became clear that change of the drop volume can be controlled small.
Wp<= (W-2delta) or -- Wp>= (W+2delta) (11)
[0179] The reason whose robustness (insensibility) over a location gap of an electrostrictive actuator improves under the above-mentioned conditions is because the support condition of an electrostrictive actuator edge becomes always fixed. That is, if electrostrictive actuator width of face is set up like drawing 25 (a) smaller than pressure room width of face so that the conditions of Wp<= (W-2delta) may be fulfilled, even if a location gap of **delta occurs, the actuator 243 of an electrostrictive actuator will not lap on the septum of the pressure room 242. Therefore, since the edge of an actuator 243 is always maintained as a revolution support condition, even if a location gap occurs, the ease of carrying out of

deformation of an electrostrictive actuator does not change a lot, and acoustic capacitance c0 serves as an almost fixed value.
[0180] On the other hand, like drawing 25 (b), since the actuator 243 has lapped on the septum of the pressure room 242 even if a location gap occurs whenever it sets up electrostrictive actuator width of face more greatly than pressure room width of face so that the conditions of Wp>= (W+2delta) may be fulfilled, even if an actuator edge is always maintained as a fixed support condition and a location gap occurs, acoustic capacitance c0 does not change a lot.
[0181] As mentioned above, if the width of face Wp of an electrostrictive actuator 241 is set up so that the conditions of a formula (11) may be satisfied so that the support condition of an actuator edge may be kept constant even if a location gap occurs, fluctuation of the acoustic capacitance c0 by location gap can be suppressed to the minimum, and it will become possible to raise the robustness over a location gap.
[0182] However, if an actuator edge is made into a fixed support condition as Wp>= (W+2delta), since deformation of an electrostrictive actuator will be restrained by the edge, as compared with the case of a revolution support condition, c0 decreases substantially. Moreover, also in Wp<= (W-2delta), if Wp is too small, regurgitation effectiveness will fall (since a substantial actuation area falls).
[0183] Drawing 27 is the result of investigating the relation between regurgitation effectiveness and variation (delta= 20 micrometers). In order to secure the robustness over a location gap and to acquire high regurgitation effectiveness from this result, it turned out that it is necessary to satisfy the following conditional expression.
0.9(W-2delta) <=Wp<= (W-2delta) (12)
[0184] In this example of an operation gestalt, since the amount delta of maximum location gaps generated at the time of junction of an electrostrictive actuator was 20 micrometers, Wp was set as 460 micrometers (the pressure room width of face W is 500 micrometers). That is, even if the **20-micrometer location gap occurred, it set up so that big effect might not occur in regurgitation effectiveness.
[0185] As a result of actually producing two or more recording heads and investigating dispersion in regurgitation effectiveness (ink droplet volume), it was checked that the difference of regurgitation effectiveness is settled to 5% or less between the heads which the delta= 20-micrometer location gap generated. Moreover, when evaluated by making a location gap increase to 30 micrometers or more intentionally, it was checked that 10% or more of difference occurs in regurgitation effectiveness. That is, it has checked that the robustness over a location gap could be improved by satisfying the conditions of a formula (12).
[0186] In addition, although it is dependent on the alignment approach at the time of junction of an electrostrictive actuator, the amount delta of location gaps of an electrostrictive actuator is set to about **10-**30 micrometers when the general alignment approach on the basis of an alignment mark is used. Therefore, as for the width of face Wp of an actuator, it is optimal to set up smaller pressure room width of face of about **10-**30 micrometers than W.
[0187] Moreover, it evaluated to the pressure room width of face W being 500 micrometers like drawing 25 (b) also about the electrostrictive actuator which set Wp as 540 micrometers. In this case, since the boundary condition of an actuator always serves as the fixed end even if a **20-micrometer location gap occurs, fluctuation of acoustic capacitance c0 can be controlled. As a result of investigating change of the drop volume by location gap, it was actually checked that the difference of regurgitation effectiveness is as small as 5% or less. However, since the boundary condition of an actuator is the fixed end, compared with the structure of drawing 25 (a), regurgitation effectiveness is 1/5 or less, and it can be told to the large drop regurgitation that it is disadvantageous structure.
[0188] In the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.5x10-20m5/N, and the inertance m0 was called for with 1.0x106 kg/m4. That is, the ink jet recording head of this example of an operation gestalt had also satisfied the conditions of a formula (8) and a formula (10), consequently drop volume 19pl (V1=30V) and 9.8 microseconds of natural periods were able to be obtained.

[0189] Example drawing 28 of the 4th operation gestalt is the top view showing the head structure of this example of an operation gestalt. The ink jet recording head of this example of an operation gestalt has the description in the point which constitutes the configuration of an electrostrictive actuator from an actuator 273, the electrode pad section 274, and the bridge section 275, although basic structure is the same as that of the example of the 3rd operation gestalt almost.
[0190] That is, it is separated into an actuator 273 and the electrode pad section 274 by formation of a through hole 278, and the electrostrictive actuator 271 is connected through the bridge section 275 in the part with the small variation rate of an actuator 273. Thereby, since the displacement constrain by the electrode pad section 274 of an electrostrictive actuator 271 is reduced, an ink jet recording head with high regurgitation effectiveness is realizable.
[0191] As expressed with the contour line 276 of drawing 28 , when the electrostrictive actuator 271 which an aspect ratio bends and deforms into the pressure room 272 near 1 is attached, an oscillating element deforms into the configuration near the spherical surface. Therefore, in the part which is more distant from the core of the oscillating section, the amount of displacement becomes small. In the case of polygons (a square, hexagon, etc.), an electrostrictive actuator 271 serves as a part which is distant from a core with the field of the angle of the oscillating section 273. Therefore, electrical-potential-difference impression (electrical connection) to an actuator 273 can be enabled by connecting the bridge section 275 with the corner of the oscillating section 273 like this example of an operation gestalt, minimizing the displacement constrain of an electrostrictive actuator 271.
[0192] As a result of carrying out regurgitation assessment of the ink jet recording head of this example of an operation gestalt, compared with the structure of drawing 25 , regurgitation effectiveness was actually able to be increased by 20%. That is, the drop volume of 23pl(s) was able to be obtained by V1=30V. In addition, it is 3.7x10-20m5/N, an inertance m0 is 1.0x106 kg/m4, and, as for the acoustic capacitance c0 of an oscillating element, the ink jet recording head of this example of an operation gestalt is also satisfied with the ink jet recording head of this example of an operation gestalt of the conditions of a formula (8) and a formula (10).
[0193] Drawing 29 is the result of structural analysis and actual regurgitation assessment investigating the relation between the width of face Wb of the bridge section, and regurgitation effectiveness. The displacement-constrain force becomes small, so that the width of face of the bridge section is small, and the inclination which increases regurgitation effectiveness can be grasped. However, when width of face of the bridge section is made [too little], a crack occurs in the bridge section at the time of manufacture or an activity, and there is a possibility that it may become impossible to perform normal expulsion of an ink droplet. Therefore, as for the width of face Wb of the bridge section, it is desirable to set to the width of face Wp of an actuator to 1/2 or less and 1/4 or more.
[0194] The configuration of an electrostrictive actuator 271 can apply various configurations, as it is not limited to a configuration like drawing 28 and shown in drawing 30 (a) - (d). That is, as long as the bridge section 275 is connected with the part which is distant from the core of an actuator 273, the configuration of the bridge section 275 or the electrode pad section 274 may be what kind of configuration, and the number of the bridge section 275 may also be 1 or plural.
[0195] Moreover, like this example of an operation gestalt, it is advantageous to separate the actuator 273 and the electrode pad section 274 of an electrostrictive actuator 271, also when performing electrical connection of an electrostrictive actuator 271. That is, in the configuration of an electrostrictive actuator 241 as shown in drawing 25 , since an actuator 243 and the electrode pad section 244 are not separated, when the electrical connection approach which used the FPC substrate shown in drawing 22 and drawing 23 is used, the jointing material for corrugated fibreboard 329 shown in drawing 23 (a) and (b) flows into an actuator field, and there is a possibility that a jointing material for corrugated fibreboard may restrain deformation of an electrostrictive actuator. Since the distance of an actuator and the electrode pad section becomes short when the high density array of the pressure room 242 is carried out especially, it becomes easy to generate the problem of such a jointing-material-for-corrugated-fibreboard inflow.
[0196] On the other hand, like this example of an operation gestalt, if it is made the configuration where

an actuator and the electrode pad section were separated, since the jointing-material-for-corrugated-fibreboard inflow to an actuator can be controlled effectively, it becomes possible to realize a reliable ink jet recording head.

[0197] In this example of an operation gestalt, the configuration of an electrostrictive actuator 271 turns into a complicated configuration as shown in drawing 28 and drawing 30 . So, sandblasting processing was used for processing of an electrostrictive actuator in this example of an operation gestalt. This becomes possible simple-wise about the electrostrictive actuator of a complicated configuration to process it into a precision for a short time, and to manufacture the ink jet of high density by low cost.

[0198] In the ink jet recording head of this example of an operation gestalt, as shown in drawing 28 , the dummy pattern 277 was arranged between the adjacent electrostrictive actuators 271. This is for preventing the effect of side etching generated at the time of sandblasting processing, and securing high dimension homogeneity to an electrostrictive actuator 271.

[0199] That is, if sandblasting processing of the electrostrictive actuator 271 is carried out, also crosswise [of an electrostrictive actuator 271] in parallel to progress of processing (etching) to the thickness direction of an electrostrictive actuator 271, processing will advance (it is hereafter called side etching). In case sandblasting processing is performed, this side etching is generated in order that a blasting particle may collide also to the side face of a piezo-electric plate. And it depends for the working speed (processing rate) of this side etching on the width of face of the processing slot formed in a piezo-electric plate. That is, if the width of face of the processing slot formed in the side of an electrostrictive actuator 271 is large, side etching will tend to advance at a quick rate, and if the width of face of a processing slot is conversely small, it will be hard coming to generate side etching.

[0200] Thus, since the speed of advance of side etching changes with processing flute widths, if the processing flute width which encloses each electrostrictive actuator 271 is not fixed, variation will arise in the speed of advance of side etching, consequently the size of an electrostrictive actuator 271 will be irregular. In order for the size of an electrostrictive actuator 271 to affect a regurgitation property greatly, it is necessary to prevent the above uneven side etching.

[0201] Then, the dummy pattern 277 is formed also between the electrostrictive actuators 271 which adjoin mutually, and it was made for the width of face of the processing slot 279 which encloses each electrostrictive actuator 271 to be fixed (about 80 micrometers) mostly in the ink jet recording head of this example of an operation gestalt. By this configuration, all the electrostrictive actuators 271 could be processed on the same conditions, and the high electrostrictive actuator 271 of dimension homogeneity was able to be realized. Specifically, the precision of the width of face Wp of an electrostrictive actuator 271 was able to be suppressed to **5 micrometers or less. When sandblasting processing is carried out without forming the dummy pattern 277, it can be told to the width of face Wp of an electrostrictive actuator 277 that the effectiveness of forming the dummy pattern 277 as compared with dispersion **20 micrometers or more having occurred is very high.

[0202] Moreover, by the same reason as the above, as shown in drawing 31 , the dummy pattern 232 was arranged also in the periphery section of the field where two or more electrostrictive actuators 231 were arranged. That is, in the electrostrictive actuator 231 located in the periphery section of the field where many electrostrictive actuators 231 were arranged, since side etching occurs remarkably, it is hard to acquire especially the dimensional accuracy as an electrostrictive actuator. Therefore, it becomes possible to secure high dimension homogeneity also in the electrostrictive actuator 231 located in the periphery section by arranging dummy PAN 232 so that the arranged electrostrictive actuator group may be surrounded. In addition, the ink jet recording head of this example of an operation gestalt is available also as a gestalt which puts the subdivided dummy pattern in order, although the dummy pattern 232 of the periphery section was made into integral construction like drawing 31 .

[0203] As a result of applying the above-mentioned dummy pattern, in the ink jet recording head of this example of an operation gestalt, it became possible in 260 ejectors in a head to suppress dispersion in a regurgitation property (drop volume, drop speed) to **5% or less. Moreover, as a result of carrying out a property comparison among two or more recording heads, it was checked that the property variation between recording heads is also settled to **6% or less, and it was proved that the above-mentioned

electrostrictive actuator structure using the dummy pattern 232 was very effective in equalization of a head property.
[0204] Example drawing 42 of the 5th operation gestalt is drawing showing the example of an operation gestalt of the ink jet recording device concerning this invention. The ink jet recording apparatus 420 of this example of an operation gestalt is constituted including the vertical-scanning device 423 for conveying the horizontal-scanning device 422 for scanning carriage 421 to the carriage 421 which carries an ink jet recording head, and the main scanning direction shown by the arrow head 428, and the record form 424 as a record medium in the direction of vertical scanning shown by the arrow head 429.
[0205] An ink jet recording head is carried on carriage 421 so that the field in which the nozzle was formed may counter with the record form 424, and it records to the fixed band field 427 by carrying out the regurgitation of the ink droplet to the record form 424, being conveyed in a main scanning direction 428. Subsequently, the next band field is recorded, conveying the record form 424 in the direction 429 of vertical scanning, and conveying carriage 421 to a main scanning direction 428 again. By repeating such actuation two or more times, image recording can be performed over the whole surface of the record form 424.
[0206] Image recording was performed using the ink jet recording device of this example of an operation gestalt, and assessment of a recording rate and image quality was actually performed. The thing of the head structure stated in the above-mentioned example of the 4th operation gestalt was used for the ink jet recording head. Full color image recording was performed by making it correspond to four colors of yellow, a Magenta, cyanogen, and black, arranging the matrix-like array head which has 260 ejectors per color side by side on carriage 421, and piling up the dot of four colors on the record form 424.
[0207] As a result of recording by large drop volume 18pl, globule volume 2pl, and record resolution setting 600dpi and a regurgitation frequency as 18kHz, the image of A4 size (210mmx297mm) could be printed by the time amount for about 5 seconds, and it was proved that a very high recording rate was realizable. Moreover, since the globule volume was as small as 2pl(s), graininess was suppressed low and the highlights section was also able to realize very high image recording of drawing quality.
[0208] The same image output experiment was conducted using the conventional head of the number 64 piece / of nozzles, and color as an example of a comparison. Since 10pl(s) of the large drop volume in which the regurgitation is possible were upper limits, record resolution was set as 1200dpi. The globule volume set 6pl(s) and a regurgitation frequency as 18kHz, respectively. As a result of evaluating a recording rate, the time amount for about 85 seconds was taken to record the image of A4 size (210mmx297mm). Moreover, since the globule volume was as large as 6pl(s), graininess was conspicuous in the highlights section and image quality was low as compared with this example of an operation gestalt.
[0209] As mentioned above, in the ink jet recording device of this example of an operation gestalt, since the acoustic capacitance c0 of the oscillating element in a recording head is set as c0 >=2.0x10-20m5/N and the pressure room of a square mold with high regurgitation effectiveness is arranged in the shape of a matrix possible [the large drop regurgitation advantageous to a low resolution], the number of nozzles can be set up greatly. Therefore, it becomes possible to increase a recording rate substantially as compared with the conventional ink jet recording device. Moreover, in the ink jet recording device of this example of an operation gestalt, since the acoustic capacitance c0 of the oscillating element in a recording head is set as c0 <=5.5x10-19m5/N, the globule regurgitation by the meniscus control system can be performed good, and high image quality can be acquired. That is, it is possible for it to be compatible in high-speed record and high-definition record in the ink jet recording device of this example of an operation gestalt.
[0210] In addition, although considered as the gestalt which records while conveying a head with carriage 421 in this example of an operation gestalt, it is also possible to apply this invention to another equipment gestalt, such as to record fixing a head and conveying only a record medium using the line mold head which has arranged the nozzle covering full [of a record medium].
[0211] As mentioned above, although each example of an operation gestalt was explained, this invention

is not limited to the configuration of the above-mentioned example of an operation gestalt. For example, although common passage and a pressure room are formed with the stainless plate in the above-mentioned example of an operation gestalt, the ceramics, glass, etc. are possible also for using other ingredients. Moreover, it is not limited to the gestalt shown in drawing 17 and drawing 18 , and the structure of the basic structure of a head, i.e., a nozzle, a supply way, and common passage, arrangement, etc. can also use other gestalten.
[0212] Moreover, in the above-mentioned example of an operation gestalt, although all the configurations of a pressure room were used as the square, even if it uses the configuration of other polygons (a triangle, a pentagon, hexagon, etc.) or an approximate circle form, the same effectiveness is acquired. Although the matrix-like array head was targetted for all the above-mentioned examples of an operation gestalt, this invention is applicable similarly to other head structures, such as head structure which arranged the pressure room in one dimension. Furthermore, in the above-mentioned example of an operation gestalt, although sandblasting processing was used for the processing approach (the manufacture approach) of an electrostrictive actuator, other processing methods, such as dicing processing and the approach of forming piezoelectric material on a diaphragm by printing, can also be used. Moreover, a diaphragm and an electrostrictive actuator can also be cast as integral construction.
[0213] Moreover, although the ink jet recording apparatus which breathes out coloring ink in the record paper and records an alphabetic character, an image, etc. on it was taken for the example in the above-mentioned example of an operation gestalt, the ink jet record in this description is limited to neither the alphabetic character in the record paper, nor record of an image. That is, the liquid which a record medium is not necessarily limited to paper, and carries out the regurgitation is not necessarily limited to coloring ink, either. For example, the thing for which this invention is used to the general drop fuel injection equipment used industrially, such as breathing out coloring ink, producing the light filter for a display, or breathing out the pewter of a melting condition on a substrate and forming the bump for component mounting on a high polymer film or glass, is also possible.
[0214] If the flat-surface configuration where it used in this example of an operation gestalt sets to A the ratios d1/d2 of the path d1 of a circumscribed circle and the path d2 of an inscribed circle which touch a flat-surface configuration besides a square oscillating element, an oscillating element of a flat-surface configuration which fills 1<=A<=2 can be used. That is, although it is A=root2 (**1.4) with a square, it is [at A= 2 and a forward hexagon] A= 1 in an equilateral triangle in A=2/root3 (**1.2) and a perfect circle. Since the minimum width of face tends to bend greatly, even if the oscillating element which has these flat-surface configurations makes the plane area as small as possible, it can maintain excluded volume. Therefore, it becomes possible to low-cost[small and]-ize a head.
[0215] In addition, if the flat-surface configuration of an oscillating element, construction material, and thickness are the structures of it not being limited to what was made as an experiment in this example of an operation gestalt, and fulfilling the conditions of 2.0x10-20 <= acoustic capacitance c0 <=5.5x10-19 m5/N, even if they are other combination, they can acquire the effectiveness concerning this invention.
[0216] As mentioned above, although this invention explained based on the suitable example of an operation gestalt, the actuation approach of an ink-jet recording head is not limited only to the configuration of the above-mentioned example of an operation gestalt by the ink-jet recording head concerning this invention and its manufacture approach, an ink-jet recording apparatus, and the list, and the actuation approach of an ink-jet recording head is also included in the range of this invention in them at the ink-jet recording head which performed various corrections and modification from the configuration of the above-mentioned example of an operation gestalt and its manufacture approach, an ink-jet recording apparatus, and a list.
[0217]
[Effect of the Invention] The manufacture approach of an ink jet recording head and the actuation approach can be acquired in the ink jet recording apparatus and list which carried the ink jet recording head which can be made to be able to breathe out the "large drop" of necessary size from the same nozzle, and can realize "nozzle increased density", and can raise the expulsion-of-an-ink-droplet effectiveness per unit area, and such an ink jet recording head, avoiding enlargement and a cost rise of

head size according to this invention, as explained above. Moreover, the both sides of the "large drop" of necessary size and a "globule" can be made to be able to breathe out selectively from the same nozzle, and the ink jet recording head which enables coexistence of high-speed record and high-definition record can be obtained. Furthermore, the shimmy of a meniscus can be prevented and an ink jet recording head with high regurgitation stability can be realized.

[Translation done.]

TECHNICAL FIELD

[Field of the Invention] This invention relates to the ink jet recording device which equipped with such an ink jet recording head the manufacture approach of an ink jet recording head and such an ink jet recording head of performing record of an alphabetic character or an image by the ink droplet which carries out the regurgitation and the actuation approach, and the list.

[Translation done.]

* NOTICES *

PRIOR ART

[Description of the Prior Art] In recent years, very small [the noise at the time of record], the non impact recording method is attracting the interest at the point in which high-speed record is possible, and the ink jet printer which used the ink jet recording method also in it has spread widely. Such an ink jet printer makes an ink droplet fly from a recording head, is made to adhere to the recording paper, is equipped with the configuration which prints an alphabetic character, a graphic form, a photograph, etc. at high speed, and it can record it, without performing fixation processing special to a regular paper etc. The drop on-demand mold ink jet method which carries out the regurgitation of the ink droplet from the nozzle which is open for free passage in a pressure room by making the pressure room where it filled up with ink generate a pressure wave (acoustic wave), using electromechanical transducers, such as an electrostrictive actuator, as the above-mentioned ink jet recording method is learned.
[0003] The ink jet recording head which adopted the drop on-demand mold ink jet method is indicated by JP,53-12138,B, JP,10-193587,A, etc. Drawing 34 is the sectional view showing the recording head of the ink jet recording device indicated by these official reports. This ink jet recording device is equipped with the pressure room 51, the nozzle 52 which is open for free passage in the pressure room 51, the ink supply way 54 to which ink is led from an ink tank through the common passage 53, and the diaphragm 55 fixed to the base of the pressure room 51.
[0004] With the above-mentioned ink jet recording apparatus, a pressure wave is generated in the pressure room 51 by carrying out the variation rate (bending deformation) of the diaphragm 55, and producing volume change in the pressure room 51 by the electrostrictive actuator 56 prepared in the pressure room 51 exteriors, at the time of expulsion of an ink droplet. By this pressure wave, it is injected outside through a nozzle 52, and some ink with which it fills up in the pressure room 51 serves as an ink droplet 57, and it flies. The ink droplet which flew reaches the target on record media, such as the recording paper, and forms a record dot (pixel). By performing formation actuation of such a record dot repeatedly based on image data, an alphabetic character and an image are recorded on a record medium.
[0005] In the ink jet recording device of the above-mentioned drop mold on demand, there is a request of reconciling high-speed record and high-definition record. However, in the conventional ink jet recording device, it was very difficult to be compatible in high-speed record and high-definition record. For example, if resolution is low stopped for implementation of high-speed record, good image quality will be spoiled, and the request of the both sides of high-speed record and high-definition record has the relation of a trade-off as high-speed record will be barred, if resolution is highly set as reverse for implementation of high-definition record.
[0006] Here, conditions required in order to reconcile the both sides of "high-speed record" and "high-definition record" with the above-mentioned ink jet recording device are explained. That is, when realizing "high-speed record", two, lowering of ** record resolution and increment (nozzle increased density) ** of the number of ** nozzles, become important conditions especially.
[0007] If "lowering of record resolution" of the above-mentioned condition ** is realized, since an unit area is recordable by few ink droplets, the time amount which record takes can be shortened. For

example, in the case of 300dpi, if the record resolution of 300dpi (dots per inch) and the record resolution of 1200dpi are measured, the number of dots required to record the same area will become 1/16 [in the case of 1200dpi]. Here, if it assumes that the frequency (drive frequency) of expulsion of an ink droplet is the same, the direction in the case of recording by 300dpi will become possible [increasing a recording rate by about 16 times].

[0008] However, since image quality will deteriorate if record resolution is set up low, there is a minimum in reduction of record resolution. If it thinks from human being's vision property, in order to realize high-speed record, without spoiling image quality (quality of an alphabetic character or a line drawing), it is optimal to set up record resolution within the limits of 300 - 600dpi (however, 1 dots per inch = 39.37 dots/(meter)) extent. That is, the direction set as record resolution lower than the record resolution (700 - 2400dpi) of the ink jet recording device used for a current general target is advantageous when raising a recording rate. However, in order to set up record resolution low, it is necessary to realize the regurgitation of a big ink droplet according to it.

[0009] That is, in order to form the big dot corresponding to the high-speed record performed in low record resolution, the regurgitation of the ink droplet with the big drop volume must be carried out. Although the relation between record resolution and the necessary drop volume changes with ink and the record paper types to be used somewhat, in order to obtain record concentration sufficient in the record resolution of 300 - 600dpi, in the case of the common ink and the common record form which are used with the conventional ink jet recording device, the ink droplet volume of 15-30pl (pico liter) is needed (however, a 1pico liter = ten to 15 m3). This is 1.5 to 3 times the value of the ink droplet volume (about 10 pl(s)) needed by record resolution 1200dpi.

[0010] Moreover, in order to make a recording rate increase, said condition ** needs "to be increased by the number of nozzles." The number of dots which can be formed in per unit time amount increases, and a recording rate improves, so that there are many nozzles. Therefore, in the usual ink jet recording apparatus, many recording heads of the multi-nozzle mold which connected two or more ink regurgitation devices (ejector) mentioned above are used.

[0011] The recording head of the above-mentioned multi-nozzle mold is shown in drawing 35 . In this recording head, the ink tank 67 has connected with the common passage 63, and two or more pressure rooms 61 are connected with this common passage 63 through the ink supply way (not shown). Thus, the number of ejectors (the number of nozzles) can be increased to about 30-100 pieces by considering as the head structure of arranging an ejector 68 in one dimension to the common passage 63.

[0012] Moreover, the ink jet recording head (it is hereafter called a matrix-like array head) which considered as the head structure which can increase the number of ejectors further, and carried out two-dimensional array of the ejector to the shape of a matrix is indicated by for example, JP,1-208146,A, the Patent Publication Heisei No. 508808 [ten to] official report, etc. The matrix-like array head indicated by drawing 36 at these official reports is shown. With this matrix-like array head, common passage consists of the mainstream way 73 and the branching passage 78, and two or more ejectors 79 are connected to each of the branching passage 78. Such matrix-like array head structure is very advantageous to the increment in the number of ejectors (the number of nozzles). For example, 260 ejectors can be made to arrange, if the number of the branching passage 78 is made into 26 and it connects ten ejectors to each branching passage 78 at a time. In addition, 36 ejectors are displayed in drawing 36 .

[0013] As mentioned above, although the matrix-like array head is advantageous to the increment in the number of nozzles, if the array consistency of a pressure room is not set up highly, the size of the whole recording head will increase, buildup of a head manufacturing cost, buildup of equipment size, or head mileage between services will increase, and the various problems of a recording rate falling will be caused. That is, the technical problem of making the number of nozzles increase by the ink jet recording head is how to be able to arrange many nozzles in a fixed area, that is, is transposed to the technical problem how a nozzle consistency can be increased. With a matrix-like array head as shown in drawing 36 , in order to make the array consistency of an ejector increase, it becomes an important technical problem to set up the size of a pressure room small.

[0014] It is desirable to, set up the path of the ink droplet which carries out the regurgitation on the other hand, as small as possible, in order for an ink jet recording device to realize "high image recording." In outputting a photograph especially, in order that the granular feeling of the highlights section (low concentration section) may influence image quality greatly, it is desirable to record the highlights section by the very small ink droplet. From the resolution of human being's eye, if the diameter of a dot is set to 40 micrometers or less, the granular feeling of an image will fall substantially, and since it will become difficult to carry out visual recognition of each dot if set to 30 more micrometers or less, image quality improves by leaps and bounds. Therefore, in the highlights section of an image, it must be desirable to realize the small dot of 30 micrometers or less of diameters, and, for that purpose, it must realize the regurgitation of the minute drop of 2 - 4pl extent.

[0015] The actuation approach for performing the minute drop regurgitation by the ink jet recording head is indicated by JP,55-17589,A. By the actuation approach given in this official report, a pressure room is once expanded just before the regurgitation, and the regurgitation of an ink droplet is performed from the condition which drew the meniscus of nozzle opening in the pressure room side. An example of an actuation wave used by this kind of the actuation approach is shown in drawing 37 . This actuation wave is constituted including the electrical-potential-difference change process 83 for expanding a pressure room, and the electrical-potential-difference change process 84 for compressing a pressure room subsequently and performing the regurgitation of an ink droplet.

[0016] Drawing 38 is the sectional view having shown typically the motion of the meniscus 92 in opening of the nozzle 91 at the time of impressing the actuation wave of drawing 37 . If the electrical-potential-difference change process 83 shown in drawing 37 is answered and a pressure room begins to expand although the meniscus 92 is carrying out the flat configuration by the initial state as shown in drawing 38 (a), when the center section of a meniscus 92 retreats more greatly than a periphery, a meniscus 92 will serve as a concave bend side configuration as shown in drawing 38 (b).

[0017] If the electrical-potential-difference change process 84 shown in drawing 37 is answered and a pressure room starts compression from the condition that the concave bend side meniscus 92 of the above was formed, as shown in drawing 38 (c), the thin liquid column 93 is formed in the center section of a meniscus 92, as further shown in drawing 38 (d), the point of a liquid column 93 will dissociate and an ink droplet 94 will be formed. The ink drop diameter at this time is almost equal to the size of the formed liquid column 93, and smaller than the diameter of a nozzle. That is, the regurgitation of the ink droplet 94 smaller than the diameter of a nozzle can be carried out by using such an actuation approach. As mentioned above, the thing of the actuation approach which controls the meniscus configuration in front of the regurgitation, and performs the minute drop regurgitation is hereafter called a "meniscus control system" on these descriptions.

[0018] As stated above, in order to realize "high-speed record" by the ink jet recording head of a drop mold on demand, the "large drop regurgitation" which enables low resolution record, and the "nozzle increased density" which enables the increment in the number of nozzles are required. On the other hand, in order to realize high-definition record, the "globule regurgitation" which enables granular feeling reduction of the highlights section is needed. Therefore, in order to reconcile the both sides of "high-speed record" and "high-definition record" by one recording head, it is necessary to satisfy simultaneously three conditions, the "large drop regurgitation", "nozzle increased density", and the "globule regurgitation."

[Translation done.]

EFFECT OF THE INVENTION

[Effect of the Invention] The manufacture approach of an ink jet recording head and the actuation approach can be acquired in the ink jet recording apparatus and list which carried the ink jet recording head which can be made to be able to breathe out the "large drop" of necessary size from the same nozzle, and can realize "nozzle increased density", and can raise the expulsion-of-an-ink-droplet effectiveness per unit area, and such an ink jet recording head, avoiding enlargement and a cost rise of head size according to this invention, as explained above. Moreover, the both sides of the "large drop" of necessary size and a "globule" can be made to be able to breathe out selectively from the same nozzle, and the ink jet recording head which enables coexistence of high-speed record and high-definition record can be obtained. Furthermore, the shimmy of a meniscus can be prevented and an ink jet recording head with high regurgitation stability can be realized.

[Translation done.]

EFFECT OF THE INVENTION

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[Translation done.]

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] However, it is very difficult in the conventional ink jet recording head to satisfy simultaneously all the "globule regurgitation" for realizing high-definition record in the "large drop regurgitation" for realizing high-speed record and "nozzle increased density", and a list.
[0020] Moreover, the unusual oscillation occurred in the meniscus at the time of expulsion of an ink droplet as another trouble in the conventional ink jet recording head, and there was a problem that the regurgitation phenomenon of an ink droplet destabilized. About the mechanism which an unusual meniscus oscillation generates, conventionally, no detailed examination is made and the prevention approach is not clarified, either. Below, it explains in accordance with the examination result by this invention persons.
[0021] Drawing 39 is a graph which shows an example of the observation of the meniscus oscillation observed by laser-doppler measurement, (a) is shown and (b) always [forward] shows the time of abnormalities, respectively. To originally a meniscus oscillation as shown in drawing 39 (a) being obtained, as shown in drawing 39 (b), the detailed oscillation was overlapped on the meniscus oscillation observed actually. If such a detailed oscillation is overlapped on a meniscus, the regurgitation of an ink droplet will become instability dramatically. In order to perform the regurgitation of a minute drop using oil-level interference of a meniscus, when the above-mentioned detailed oscillation is overlapped on a meniscus oscillation, it becomes impossible to expect the normal minute drop regurgitation -- the regurgitation of a minute drop becomes impossible or an unnecessary ink droplet is breathed out by reverse -- especially in the meniscus control system mentioned above.
[0022] This invention aims at providing with the manufacture approach of an ink jet recording head, and the actuation approach the ink jet recording apparatus which carried the ink jet recording head which can be made to be able to breathe out the "large drop" of necessary size from the same nozzle, and can realize "nozzle increased density", and can raise the expulsion-of-an-ink-droplet effectiveness per unit area, and such an ink jet recording head, and a list, avoiding enlargement and a cost rise of head size in view of the above.
[0023] Moreover, this invention makes the both sides of the "large drop" of necessary size, and a "globule" breathe out selectively from the same nozzle, and aims at offering the ink jet recording head which enables coexistence of high-speed record and high-definition record. Further, this invention prevents the shimmy of a meniscus and aims at realizing an ink jet recording head with high regurgitation stability.

[Translation done.]

* NOTICES *

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1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

MEANS

[Means for Solving the Problem] Although it is very difficult to be simultaneously satisfied with the conventional ink jet recording head of three conditions of "nozzle increased density" in addition to implementation of the "large drop regurgitation" from the same nozzle, and the "globule regurgitation", an example is explained below, citing the reason. First, considering the "large drop regurgitation", the volume of the maximum ink droplet which can carry out the regurgitation in an ink jet recording head is mostly in agreement with volume variation (excluded volume) deltaV which generates a pressure room so that it may mention later (refer to formula (2)). That is, it is necessary to make the pressure interior of a room generate a volume change almost equivalent to the ink droplet which carries out the regurgitation. Therefore, in order to obtain the big drop volume, it is necessary to increase the actuation area (area of base of a pressure room) of an electrostrictive actuator, and to increase deltaV.
[0025] For example, when the amount of displacement of an electrostrictive actuator is set to 0.1 micrometers, the regurgitation of drop volume 10pl can be performed in about two 1x10 to 7 m actuation area, but when you are going to make it increase the drop volume to 20pl(s), a twice [about] as many actuation area (2x10 to 7 m2) as this is needed. consequently, the number of nozzles per unit area (nozzle consistency) -- about -- it will decrease to one half. That is, if low resolution record tends to be realized and it is going to enlarge the drop volume for high-speed record, the size of a pressure room will increase and a nozzle consistency will fall as the result. Thus, since the "large drop regurgitation" and "nozzle increased density" have the relation of a trade-off, it is very difficult to realize simultaneously low resolution record and the increment in the number of nozzles (nozzle increased density).
[0026] Next, the "globule regurgitation" is considered. Since it is shown below in order for a meniscus control system to perform the minute drop regurgitation, it is necessary to set up short the natural period Tc of the pressure wave which the pressure interior of a room is made to generate. That is, with a meniscus control system, as drawing 38 explained, after drawing a meniscus 92 in a pressure room side first and making a meniscus 92 into a concave bend configuration, the thin liquid column 93 is formed by extruding a meniscus 92 toward a nozzle outside. It was shown clearly that the size of the liquid column which this invention persons examine the formation mechanism of a liquid column 93 in a detail, consequently is formed is dependent on the oil-level rate at the time of extruding a meniscus.
[0027] Drawing 32 is the sectional view having shown typically the behavior of the meniscus at the time of using a meniscus control system. Namely, if a pressure is applied in the direction extruded outside to the meniscus 92 of a concave bend side configuration, each part of a meniscus 92 tends to move in the direction of a normal of an oil level, as shown in drawing 32 (a). Consequently, a lot of ink focuses on a nozzle center section, and a liquid column 93 is formed in the center section of the nozzle 91 of this local increment in the volume. Since the increment rate in the volume in a nozzle center section also becomes large at this time so that the passing speed of an oil level is quick, the very thin liquid column 93 is formed with a quick growth rate. On the contrary, since the rate of the increment in the volume also becomes small as shown in drawing 32 (b) when the passing speed of an oil level is slow, a liquid column 93 becomes thick and a growth rate becomes small.

[0028] The drop diameter of the ink droplet 94 breathed out with a meniscus control system is mostly in agreement with the size of the liquid column 93 formed. Moreover, the flight rate (drop speed) of an ink droplet is mostly in agreement with the growth rate of a liquid column 93. Therefore, in order to make the minute ink droplet 94 fly at high speed, the above-mentioned oil-level passing speed is made to increase, and it becomes important conditions to produce the rapid increment in the volume in the nozzle center section. Here, the natural period Tc of a pressure wave is governing oil-level passing speed. That is, the velocity of vibration of the meniscus 92 at the time of expulsion of an ink droplet is dependent on the natural period Tc of a pressure wave, and it increases, so that a natural period Tc is short, the velocity of vibration, i.e., the oil-level passing speed, of a meniscus. Therefore, when carrying out the regurgitation of the minute drop with a meniscus control system, it becomes so advantageous that the natural period Tc of a pressure wave is short.
[0029] Drawing 33 is a graph which indicates the result of having investigated relation with the natural period Tc of a pressure wave to be the minimum drop diameter acquired with a meniscus control system. This graph shows that the minimum drop diameter decreases, so that a natural period becomes short. Although it is dependent on the diameter of a nozzle, ink viscosity, etc., the minimum ink droplet volume obtained needs to set a natural period Tc as 12 or less microseconds still more desirably 15 or less microseconds by the general ink jet recording head whose viscosity of the ink which the diameter of a nozzle is 20-30 micrometers, and uses is 2-5cps, in order to make possible the regurgitation [the minute drop of 2-4pl suitable for high-definition record].
[0030] However, the "large drop regurgitation" and reciprocity relation which were described previously have reduction of a natural period Tc. That is, if the size of a pressure room is greatly set up in order to realize the "large drop regurgitation", the natural period of a pressure wave will become very long. This is because a natural period Tc becomes long depending on the acoustic capacitance sum (c0+c1) of a pressure room and an oscillating element (diaphragm + electrostrictive actuator) with the big pressure room and big oscillating element of size suitable for the "large drop regurgitation" as for the natural period Tc of a pressure wave. For example, although it is easy to realize the ink jet recording head whose large drop volume is 10pl(s) and whose natural period is 10 microseconds, if it is going to increase the large drop volume to 20pl(s), a natural period Tc will be set to about 20 twice [about] as many microseconds as this.
[0031] Then, this invention persons receive having performed adjustment of the drop volume and a natural period Tc conventionally, combining the parameter of a large number in connection with head structure by trial and error. In the ink jet recording head using the electrostrictive actuator which bends and deforms from various experimental results That the substantial parameter which governs the drop volume and a natural period Tc is only the acoustic capacitance of an oscillating element by specifying the range where the acoustic capacitance of a header and an oscillating element is proper It came to invent this invention which realizes coexistence and "nozzle increased density" of the "large drop regurgitation" of necessary size, and the "globule regurgitation."
[0032] In order to attain the above-mentioned object, the ink jet recording head concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By generating a pressure wave in the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up It is the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle, and acoustic capacitance of said oscillating element is characterized by being more than 2.0x10-20m5/N.
[0033] The acoustic capacitance (c0) of an oscillating element is a parameter showing the rigidity of an oscillating element, an oscillating element tends to bend, namely, that c0 is large means that it is easy to generate the big excluded volume of a pressure room. The value of various experimental results and structural-analysis results which are mentioned later to 2.0x10-20m5/N can be said to be the value optimal as a lower limit of acoustic capacitance c0 from a viewpoint that the regurgitation of the "large drop" of 15 or more pls required for low resolution record of 600 or less dpi is realizable.

[0034] For example, characterization was carried out to each about the example which changed variously thickness tp of an electrostrictive actuator, the thickness tv of a diaphragm, and the pressure room width of face W. Consequently, acoustic capacitance c0 >=2.0x10-20[m5/N]
although the regurgitation of the "large drop" of 15 or more pls was able to be carried out under ******
-- acoustic capacitance c -- 0< 2.0x10-20 [m5/N]
Under ******, the regurgitation of the "large drop" of 15 or more pls could not be carried out, and sufficient image concentration was not able to be obtained.
[0035] That is, in this invention, by having specified the acoustic capacitance c0 of an oscillating element more than 2.0x10-20m5/N, the excluded volume of 15 or more pls by the oscillating element can be obtained, and the regurgitation of the large drop of 15 or more pls can be carried out from one nozzle.
[0036] It is desirable to set the upper limit of the acoustic capacitance of an oscillating element as 5.5x10-19m5/N in the desirable ink jet recording head of this invention. Although this invention persons could realize the "large drop regurgitation" by setting acoustic capacitance c0 as the value more than 2.0x10-20m5/N, when acoustic capacitance c0 was too large, the natural period of the pressure wave generated in the pressure interior of a room increased, and they confirmed that the evil of it becoming impossible to perform the "globule regurgitation" occurred. And based on the various experimental results mentioned later, it hit on an idea by setting the upper limit of acoustic capacitance c0 as 5.5x10-19m5/N to prevent generating of the above-mentioned evil.
[0037] For example, although the "large drop" of 15 or more pls was able to carry out the regurgitation when the regurgitation experiment was conducted under the conditions of acoustic capacitance c0>5.5x10-19m5/N, the regurgitation of the "globule" of 4 or less pls was not able to be carried out. In order to secure large drop volume of 15 or more pls and to obtain globule volume of 4 or less pls from this result, it checked that it was optimal to set the acoustic capacitance c0 of an oscillating element to more than 2.0x10-20m5/N and below 5.5x10-19m5/N.
[0038] In the desirable ink jet recording head of this invention, the control of a driver voltage wave impressed to said oscillating element is answered, and the drop volume of the ink droplet which carries out the regurgitation from said nozzle changes to a multistage story. In this case, since the low resolution record by the large drop and the high-definition record by the globule are simultaneously realizable, the effectiveness that it is compatible in high-speed record and high-definition record is acquired.
[0039] Moreover, it is desirable that the maximum drop volume of the ink droplet which carries out the regurgitation from said nozzle is set as 15 or more pls. In this case, since it becomes possible to set record resolution as 600 or less dpi, the effectiveness that a recording rate can be increased is acquired. The driver voltage wave impressed at the time of the regurgitation of the ink droplet of 15 or more pls should be constituted including at least the 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which shrinks the volume of said pressure room, and making an ink droplet breathing out, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.
[0040] Or it is also a desirable mode that the minimum drop volume of the ink droplet breathed out from said nozzle is 4 or less pls. In this case, in the highlights section, the low smooth image recording of graininess becomes possible, and the effectiveness that high-definition record is realizable is acquired. The driver voltage wave impressed at the time of the regurgitation of the ink droplet of 4 or less pls The 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room, By forming the liquid column which impresses an electrical potential difference in the direction which compresses the volume of said pressure room, and has a path smaller than the diameter of opening of said nozzle in said nozzle, and making an ink droplet separate from the head of this liquid column It should constitute including the 2nd electrical-potential-difference change process for performing the regurgitation of a minute ink droplet at least.
[0041] Furthermore, the aspect ratio in said pressure room and each flat-surface configuration of an

electrostrictive actuator is preferably set as abbreviation 1, respectively. The "aspect ratio" in this invention means the ratio of the longest width of face in the flat-surface configuration of an oscillating element, and the shortest width of face. If an aspect ratio is set as abbreviation 1, the regurgitation effectiveness per unit area can be maximized and it will become possible to realize an ink jet recording head with a high nozzle consistency. As a flat-surface configuration of an oscillating element, it can choose any of an abbreviation equilateral triangle, an abbreviation square, an approximate regular hexagon, and an approximate circle form they are.
[0042] It is desirable to set the flat-surface dimension (plane area) of a pressure room as 2 0.09-0.5mm, and to set the thickness of a diaphragm and an electrostrictive actuator as 5-20 micrometers and 15-40 micrometers here, respectively. Thereby, in the ink jet recording head in which an aspect ratio has the pressure room of abbreviation 1, the acoustic capacitance c0 of an oscillating element can be set to more than 2.0x10-20m5-/N and below 5.5x10-19m5-/N, and the effectiveness that it is compatible in the "large drop regurgitation" and the "globule regurgitation" is acquired.
[0043] Here, as for the acoustic capacitance of an oscillating element, it is desirable to be set up more greatly than the acoustic capacitance of a pressure room. In this case, the shimmy of a meniscus can be controlled, an oscillation of a meniscus can be normalized and the effectiveness that the stability of expulsion of an ink droplet can be improved can be acquired.
[0044] moreover -- if the inertance of cc and said oscillating element is set [the natural period of the pressure wave generated in said pressure interior of a room] to m0 for the synthetic acoustic capacitance of Tc, said oscillating element, and a pressure room -- a degree type -- m0<2.5x10-4Tc2/cc [kg/m4]
It is a desirable mode that it is also satisfied. Excitation of the vibration system which is inherent in an ink jet recording head can be controlled by this, the effect of the above-mentioned meniscus shimmy can be controlled further, and it becomes possible to realize the ink jet recording head excellent in regurgitation stability.
[0045] When width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room, and the core of the actuator of said electrostrictive actuator, they are degree type Wp<= (W-2delta) or Wp>= (W+2delta).
It is desirable that it is satisfied. In this case, the support condition of an electrostrictive actuator edge becomes always fixed, and the robustness (insensibility) over a location gap of an electrostrictive actuator improves.
[0046] Moreover, when width of face of delta and said electrostrictive actuator is set [the width of face of said pressure room] to Wp for the amount of location gaps of the core of W and said pressure room, and the core of the actuator of said electrostrictive actuator, it is degree type 0.9(W-2delta) <=Wp<= (W-2delta).
It is a desirable mode that it is also satisfied. Thereby, even when junction location gap occurs between an electrostrictive actuator and a pressure room, it can prevent that the big change in regurgitation effectiveness arises, and it becomes possible to secure still higher regurgitation effectiveness.
[0047] It is desirable that the ink droplet breathed out from said nozzle reaches the target on a record medium in the record resolution of 600 or less dpi. In this case, since quality, such as an alphabetic character recorded, is also securable while the number of dots which is needed for record can be lessened and it becomes advantageous to high-speed record, the effectiveness that coexistence of high-speed record and high-definition record is attained is acquired. Moreover, it is also a desirable mode that the natural period Tc of the pressure wave generated in said pressure interior of a room is set as 15 or less microseconds. In this case, it becomes possible to carry out the regurgitation of the small ink droplet of a path with a meniscus control system, and the effectiveness that image quality can be improved is acquired in the output of a photograph etc.
[0048] Moreover, it is also a desirable mode that said electrostrictive actuator is equipped with the actuator stationed to the field equivalent to said pressure room, the electrode pad section arranged to the field equivalent to the outer wall of said pressure room, and the bridge section which connects the both sides of said actuator and said electrode pad section. The phenomenon in which deformation of an

electrostrictive actuator is barred by the electrode pad section can be controlled by this, and it becomes possible to realize an ink jet recording head with high regurgitation effectiveness. If said bridge section is connected with the location distant from the core of said actuator, the restraint over deformation of said actuator can be minimized and the effectiveness that the regurgitation effectiveness of a head can be increased can be acquired.

[0049] Moreover, it is also a desirable mode that two-dimensional array of said nozzle is carried out to the shape of a matrix. In this case, since it becomes possible to increase the number of nozzles in a head, the effectiveness that a recording rate can be increased substantially is acquired.

[0050] A dummy pattern is arranged so that the periphery section of the electrostrictive actuator field where two or more arrays of the electrostrictive actuator were carried out may be surrounded preferably. Thereby, in case an electrostrictive actuator is processed by the sandblasting processing method, aggravation of the process tolerance resulting from side etching can be prevented, and the effectiveness that an ink jet recording head with the high homogeneity of a regurgitation property is realizable is acquired. A dummy pattern can be arranged also between the electrostrictive actuators in the interior of an electrostrictive actuator field. In this case, the effectiveness that the effect of the above-mentioned side etching can be controlled further is acquired.

[0051] In the desirable ink jet recording head of this invention, it has the wiring substrate with which the signal line was formed, this wiring substrate is arranged in a wrap location in the upper part of said electrostrictive actuator by which matrix arrangement was carried out two-dimensional, and said electrostrictive actuator and said wiring substrate are electrically connected through the bump. Thereby, also in the matrix-like array head which carried out the high density array, positive electrical connection becomes possible to each electrostrictive actuator. That is, since a signal line can be arranged to a plane different from an oscillating element, arrangement of a signal line does not spoil the high density array of a pressure room, and the high density array of a pressure room is attained.

[0052] Moreover, it is desirable that said bump is constituted with conductive core material and the jointing material for corrugated fibreboard which carried out the coat to the periphery section of this core material. In this case, since it becomes possible to form a gap between an electrostrictive actuator and a wiring substrate after electrical connection, the poor property of the electrostrictive actuator resulting from contact to an electrostrictive actuator and a wiring substrate can be prevented, and a reliable ink jet recording head can be realized. Furthermore, it is desirable that said core material is formed in the shape of a semi-sphere. In this case, the contact condition of an electrostrictive actuator and a bump can be equalized, and while the stable electrical connection becomes possible, the effectiveness that destruction of the electrostrictive actuator at the time of electrical connection can be prevented is acquired. As for said wiring substrate, it is desirable that a resin base material and a metallic conductor are included. In this case, the contact condition of an electrostrictive actuator and a bump can be equalized further.

[0053] The manufacture approach of the ink jet recording head concerning this invention is the manufacture approach of manufacturing said ink jet recording head, and is characterized by carrying out patterning by sandblasting processing of said electrostrictive actuator.

[0054] By the manufacture approach of the ink jet recording head concerning this invention, since patterning of an electrostrictive actuator is performed by sandblasting processing, the electrostrictive actuator of a complicated configuration suitable for maximization and electrical connection of regurgitation effectiveness is realizable with close dimensional accuracy and a low manufacturing cost.

[0055] The ink jet recording apparatus concerning this invention is characterized by having said ink jet recording head. According to such an ink jet recording apparatus, an ink jet recording apparatus compatible in a high recording rate and high drawing quality is realizable.

[0056] The actuation approach of the ink jet recording head of the 1st view concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and

said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of setting up the acoustic capacitance of said oscillating element more than 2.0x10-20m5/N, impressing an electrical potential difference in the direction which makes said oscillating element contracting the volume of said pressure room, and making an ink droplet breathing out, It is characterized by carrying out the regurgitation of the ink droplet of 15 or more pls by impressing a driver voltage wave including the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room.

[0057] By the actuation approach of the ink jet recording head of the 1st view of this invention, the effectiveness that the regurgitation of an ink droplet with the big drop volume which is needed for low resolution record of 600 or less dpi is realizable good is acquired.

[0058] The actuation approach of the ink jet recording head of the 2nd view concerning this invention A nozzle, the pressure room which is open for free passage for this nozzle, and the diaphragm which forms a part of wall surface of this pressure room, By compressing the ink with which it had the electrostrictive actuator joined to said diaphragm so that it might correspond to said pressure room, and the oscillating element which consists of said diaphragm and said electrostrictive actuator deformed, and said pressure interior of a room was filled up In the actuation approach of driving the ink jet recording head in which an ink droplet carries out the regurgitation from said nozzle The 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which the acoustic capacitance of said oscillating element is set [direction] to more than 2.0x10-20m5/N and below 5.5x10-19m5-/N, and expands the volume of said pressure room to said oscillating element, By impressing an electrical potential difference in the direction which compresses the volume of said pressure room, and impressing a driver voltage wave including the 2nd electrical-potential-difference change process for forming the liquid column of a path smaller than the diameter of opening of this nozzle in said nozzle, making an ink droplet separate from the head of this liquid column, and performing the regurgitation of a minute ink droplet It is characterized by carrying out the regurgitation of the ink droplet of 4 or less pls.

[0059] By the actuation approach of the ink jet recording head of the 2nd view of this invention, the effectiveness that image recording with the low high drawing quality of graininess is realizable is acquired.

[0060]

[Embodiment of the Invention] It precedes explaining the example of an operation gestalt of the ink jet recording head concerning this invention, and the relation between the operating characteristic of an oscillating element and the ink droplet volume is explained first. That is, although it is a mechanical system since an oscillating element generates a physical oscillation when it is seen in phenomenon, the ink jet recording head is intermingled for them and equipped with the acoustical system of ink passage, and the electric system of an actuation circuit besides the mechanical system. Since the differential equation description is a highly uniform, equivalent transformation of the these 3 system can be carried out mutually. Therefore, all are unified into an acoustical system here and actuation of a recording head is considered as one acoustic circuit.

[0061] A mechanical system can express the operating characteristic of an oscillating element (diaphragm + electrostrictive actuator) only with mass [kg], compliance [m/N], and three parameters of attenuation [Ns/m]. If equivalent transformation of these is carried out to an acoustical system, the operating characteristic of an oscillating element can be expressed only with an inertance m0 [kg/m4], acoustic capacitance c0 [m5/N], and three parameters of acoustic resistance r0 [Ns/m5].

[0062] If the above-mentioned acoustical system parameter is used, one oscillating element can be expressed as an equal circuit (acoustic circuit) shown in drawing 1 . Here, psi expresses a pressure [Pa]. Moreover, drawing 2 (a) is the equal circuit which connected the passage system with the oscillating element, and transposes the ink jet recording head shown in drawing 34 to an equal circuit.

[0063] It is here, and in an oscillating element and 1, a pressure room and 2 mean an ink supply way,

and 3 means [u / [m3/s], volume velocity, and 0 of a subscript] the nozzle, respectively. Head properties, such as ink droplet volume, drop speed, and a natural period of a pressure wave, can be searched for by analyzing this circuit using a circuit simulator etc. and investigating change of the volume velocity u3 of the nozzle section.

[0064] Drawing 3 (a) - (c) is the result of investigating the relation between the acoustic capacitance c0 of an oscillating element, an inertance m0 and acoustic resistance r0, and excluded volume deltaV using the equal circuit of drawing 2 (a), respectively. In addition, excluded volume deltaV is a parameter which is mostly in agreement with the drop volume q so that it may mention later. From this result, to hardly affecting excluded volume deltaV (drop volume q), c0 is large to deltaV, m0 and r0 influenced, and the inclination which deltaV increases became clear, so that c0 was large. That is, it became clear that only c0 influences a regurgitation property (drop volume q) among the acoustic capacitance c0 of an oscillating element, an inertance m0, and acoustic resistance r0.

[0065] Since the inertance m0 and acoustic resistance r0 of an oscillating element cannot have big effect on a regurgitation property (drop volume) and the acoustic capacitance c3 of a nozzle can also be disregarded to the acoustic capacitance c0 of an oscillating element, and the acoustic capacitance c1 of a pressure room, the circuit of drawing 2 (a) can be simplified like drawing 2 (b). Here, it assumes that the relation of m2=k-m3 and r2=k-r3 is realized, and when theoretical analysis is performed about the case where the step-function-pressure psi is inputted, the volume velocity u3 in the nozzle section is expressed to the inertance and acoustic resistance in a nozzle and a supply way like a degree type.

[0066]

[Formula 1]

$$u_3(t)=\frac{c_0\,\psi}{cm_3\,E_c}\exp(-D_c\cdot t)\sin(E_c\cdot t) \qquad (1)$$

$$c=c_0+c_1$$

$$E_c=\sqrt{\frac{1+\frac{1}{k}}{cm_3}-D_c^2}$$

$$D_c=\frac{r_3}{2m_3}$$

[0067] Since volume [of the ink droplet (large drop) breathed out from a nozzle] q [m3] is almost equal to the area of the slash section shown in drawing 39 (a), q is expressed by the degree type.

[0068]

[Formula 2]

$$q=\int_0^{t_m} u_3\,dt \qquad (2)$$

$$\approx 2\frac{m_2}{m_2+m_3}\cdot V\cdot\phi\cdot c_0$$

$$=2\frac{m_2}{m_2+m_3}\cdot\Delta V$$

[0069] phi [Pa/V] is an electroacoustic transduction multiplier (= psi/V), and is a parameter showing the magnitude of the pressure generated in per unit electrical potential difference. In the ink jet recording head using the electrostrictive actuator which carries out bending deformation, this electroacoustic transduction multiplier phi is a very important parameter which influences the drop volume (regurgitation effectiveness). However, about the relation between head structure and phi, there is no example investigated in detail in the past. Then, this invention persons investigated about the relation

between head structure and phi by structural analysis which used the finite element method.
[0070] What is necessary is just to use the following approaches, in order to ask for phi by structural analysis. First, an oscillating element is modeled and the deformation condition of the oscillating element at the time of impressing applied voltage V is searched for. Next, a pressure is applied to an oscillating element and it asks for the pressure p required in order to return the deformation of an oscillating element to zero. Based on the value of this p, the value of phi is calculated as phi=p/V. Moreover, the acoustic capacitance c0 of an oscillating element is similarly computed as c0=deltaV/p by asking for excluded volume deltaV generated when a pressure p is applied and an oscillating element is made to deform.
[0071] Drawing 4 (a) is a graph which shows the result of having changed each parameter in connection with head structure in the large range, having performed structural analysis, and having calculated the value of c0 and phi. It is the range of 9x10-8 to 1x10 to 6 m2 about a pressure room and the area in the plane view of an electrostrictive actuator, and, specifically, the aspect ratio in a pressure room and the flat-surface configuration of each electrostrictive actuator was changed in 1-20. Moreover, in metal plates, such as stainless steel, it changed in 5-20 micrometers, and diaphragm thickness was changed in 20-100 micrometers with the polyimide film. Furthermore, electrostrictive actuator thickness was changed in 10-50 micrometers, the piezoelectric constant was changed, respectively in the range of 1x10-10 - 3x10-10 m/V, structural analysis was performed to various combination, and the value of phi and c0 was calculated. Consequently, as for acoustic capacitance c0, it became clear that 1x10-21 - 5x10-18m5/N and phi changed in the range of 4x103 - 4x104 Pa/V.
[0072] The result of having investigated relation with phi-c 0 (the parameter which determines the drop volume per unit electrical potential difference; referring to said formula (2)), andc0 based on the above-mentioned analysis result is shown in drawing 4 (b). Although the relation between c0 and phi-c 0 is distributed within the limits of the slash section in a graph from this result, in order to obtain the big drop volume (big phi-c 0) as a generality, it is c0 >=2.0x10-20[m5/N].
It became clear that it is necessary to set up.
[0073] That is, in order to secure the big drop volume (regurgitation effectiveness) in the ink jet recording head which bent and used the deforming electrostrictive actuator, it is c0 >=2.0x10-20[m5/N].

** -- it becomes important conditions. Acoustic capacitance c0 is a parameter showing the rigidity of an oscillating element, an oscillating element tends to bend, namely, that c0 is large means that it is easy to generate big excluded volume deltaV. Moreover, the value of 2.0x10-20m5/N can be said to be the value for which it was suitable as a lower limit of acoustic capacitance c0 also from a viewpoint of obtaining the large drop of 15 or more pls which enables low resolution record of 600 or less dpi so that it may state below.
[0074] When a diaphragm is constituted from metallic materials (stainless steel, nickel, etc.) and a piezoelectric constant is made into abbreviation 3x10-10 m/V as conditions the most suitable when producing a actual ink jet recording head, and general, the relation between c0 and phi-c 0 comes to be shown in drawing 5 and drawing 6 .
[0075] Another graph with which drawing 5 shows the relation between c0 and phi-c 0, and drawing 6 are the graphs to which a part of drawing 5 was expanded. That is, when diaphragm construction material and a piezoelectric constant were fixed, even if it changed values, such as diaphragm thickness, electrostrictive actuator thickness, and an aspect ratio, it became clear that the relation between c0 and phi-c 0 is plotted on about one curve. It means that this, i.e., phi among the parameters which govern the drop volume q, can be treated as a function of c0.
[0076] In a general ink jet recording head, m2 and m3 in said formula (2) are set up with m2**m3 so that it may mention later. Moreover, if applied voltage V considers an actuation circuit and power-source cost, about 40V will become an upper limit. Therefore, among the parameters of a formula (2), since m2/(m2+m3) and applied voltage V are parameters actually unchangeable into arbitration and phi is a parameter depending on c0, it can be said that the parameter which is governing the drop volume q is only c0 substantially.

[0077] Then, c0 [required to obtain drop volume of 15 or more pls from the result of drawing 6] is calculated. As mentioned above, since it can place with m2/(m2+m3) **1/2, and V<=40 [V], in order to secure drop volume of 15 or more pls, it is necessary to set up phi-c 0 more than 4x10-16m3/V. If this is applied to the graph of drawing 6 , it will become the conditions of c0 >=2.0x10-20m5/N. That is, c0 >=2.0x10-20m5/N serves as important conditions also from a viewpoint of obtaining drop volume of 15 or more pls which was suitable for low resolution record by the ink jet recording head which bent and used the deforming electrostrictive actuator.
[0078] As stated above, it bends and the point of having specified the header and the proper lower limit of c0 for the substantial parameter which governs the drop volume in the ink jet recording head using the deforming electrostrictive actuator being only c0 is one of the descriptions of this invention. It is very effective to have arranged the rule parameter only to one of the c0 as mentioned above, and to have clarified the optimal range to conventionally having adjusted the drop volume, combining the parameter of a large number in connection with head structure by trial and error, when performing the optimization design of a head.
[0079] Next, the pressure room configuration of reconciling the "large drop regurgitation" and "nozzle increased density" is considered. Since the parameter which is governing the drop volume substantially is only c0 as mentioned above, in order to reconcile the "large drop regurgitation" and "nozzle increased density", it is important to maximize c0 per unit area.
[0080] It depends for acoustic capacitance c0 on the configuration of an oscillating element greatly. Then, it investigated about the oscillating element configuration which can maximize c0 per unit area. Drawing 7 is the result of calculating c0 from each configuration from which area is the same as that of, and an aspect ratio (aspect ratio) differs about a square pressure room. Drawing 7 shows that acoustic capacitance c0 increases, so that the aspect ratio of the flat-surface configuration of a pressure room approaches 1 (i.e., so that it is a configuration near a square). That is, if the pressure room of a flat-surface configuration with the aspect ratio near 1 is used, it will become possible to obtain the big acoustic capacitance c0 in a small occupancy area, and will become advantageous to improvement in a nozzle consistency.
[0081] In order to set up the regurgitation effectiveness per unit area highly from the result shown in drawing 7 , it is required to set up the aspect ratio of a pressure room between 0.3-3 at least. Furthermore, it is desirable to set up an aspect ratio between 0.8-1.2. In this case, an aspect ratio = as compared with the optimum conditions of 1, decline in regurgitation effectiveness can be dedicated to 30% or less.
[0082] Here, an "aspect ratio" means the value which shows the ratio (B/A) of the longest width of face (A) in the flat-surface configuration of a pressure room, and the shortest width of face (B), as shown in drawing 8 (a) - (d) explaining the definition of an aspect ratio. Moreover, when the aspect ratio of the flat-surface configuration of a pressure room is set as abbreviation 1, the aspect ratio of an oscillating element also usually serves as abbreviation 1. That is, the oscillating element consists of actuators (after-mentioned) of a diaphragm and an electrostrictive actuator, and since the actuator of an electrostrictive actuator is made into the flat-surface configuration of a pressure room, and a configuration mostly in agreement, the aspect ratio of an oscillating element also serves as abbreviation 1.
[0083] Although drawing 7 is the result of investigating about a square pressure room, the same result that c0 becomes max by aspect ratio =1 is obtained also about the polygon containing the other triangle, a pentagon, and a hexagon, and the ellipse form. Therefore, an aspect ratio = generally the conclusion that 1 is the optimal is appliable also about the pressure room of other configurations other than a square.
[0084] Next, the cause of the unusual meniscus oscillation shown in drawing 39 (b) is described. Drawing 9 is a graph which shows the result of having investigated the frequency response of the equivalence electrical circuit of drawing 2 (a). Since the peak exists in 130kHz and 1.3MHz in this graph, as for this circuit, it turns out that it has two resonance frequency. Drawing 10 is the circuit diagram which rewrote the equivalence electrical circuit of drawing 2 (a) and in which showing the equivalence electrical circuit of one ejector. When a circuit is rewritten in this way, it turns out that the

two vibration system A and B is included in this circuit.
[0085] That is, it is possible that two resonance frequency looked at by drawing 9 is equivalent to each resonance frequency of vibration system A and B. It generates according to vibration system A, and the original meniscus oscillation used for expulsion of an ink droplet can understand generating of a meniscus oscillation like drawing 39 (b), if it thinks that the short oscillation of the period by vibration system B is overlapped on this. The natural period Tc of vibration system A is expressed like a degree type.
[0086]
[Formula 3]

$$T_c=2\pi\sqrt{\frac{m_2\,m_3}{m_2+m_3}\cdot(c_0+c_1)} \qquad (3)$$

[0087] The point that c0 and c1 are parallel connection in vibration system A is characteristic, therefore the natural period Tc of a meniscus oscillation is c (=c0+c1).
It rules "Be alike" over. On the other hand, the natural period TB of vibration system B is expressed like a degree type.
[0088]
[Formula 4]

$$T_B=2\pi\sqrt{m_0\cdot c_c} \qquad (4)$$

[0089] cc in a formula 4 is the synthetic acoustic capacitance at the time of carrying out the series connection of the acoustic capacitance c0 of an oscillating element, and the acoustic capacitance c1 of a pressure room, and is expressed with a degree type.
[0090]
[Formula 5]

$$c_c=\frac{1}{\frac{1}{c_0}+\frac{1}{c_1}} \qquad (5)$$

[0091] That is, the point that the synthetic acoustic capacitance cc to which the series connection of c0 and c1 was carried out rules over is the description of vibration system B. This vibration system B differs from the natural frequency of the oscillating element itself seen by the ink jet recording head using the longitudinal-oscillation mold electrostrictive actuator indicated by JP,6-171080,A etc. Vibration system B is one of the vibration system formed by connecting an oscillating element and a passage system (pressure room) to the last instead of the natural-frequency system of the oscillating element itself.
[0092] As mentioned above, it bends, and in the deforming electrostrictive actuator, since two vibration system exists in a recording head, in order to obtain a normal meniscus oscillation, it is required to control the effect of the above-mentioned vibration system B. It is necessary to fulfill two conditions which make the vibration amplitude of vibration system B small (conditions 1), and make it TB<<Tc (conditions 2) for this implementation. Hereafter, the concrete cure for fulfilling two conditions is described.
[0093] The response of the vibration system B when inputting the step-function-pressure psi can be expressed like a degree type.
[0094]
[Formula 6]

$$u_B(t)=\frac{\psi}{m_0 E_0}\exp(-D_B\cdot t)\sin(E_B\cdot t) \qquad (6)$$

$$\approx\psi\cdot\sqrt{\frac{c_c}{m_0}}\exp(-D_B\cdot t)\sin(E_B\cdot t)$$

$$E_B=\sqrt{\frac{1}{c_c m_0}-D_B^2}$$

$$D_B=\frac{r_0}{2m_0}$$

[0095] That is, since the amplitude of the volume velocity uB produced according to vibration system B is proportional to the 1-/square of cc, in order to make the amplitude of vibration system B small, it needs to set up (conditions 1) and cc small. However, in order to make it not affect the amplitude or natural period of an original meniscus oscillation (vibration system A), it is c (=c0+c1).
** -- it is necessary to minimize cc under certain conditions
[0096] Drawing 11 is a graph which shows the change of cc by the value of c0. In this graph, it calculated as c0+c1=10. This graph shows that what is necessary is just to set c0 and c1 as imbalance (out of balance) with setting out, c0>c1 [i.e.,], or c0<c1, in order to make cc small. However, it needs to be referred to as c0>c1, in order to reconcile the both sides of reservation of the drop volume, and amplitude reduction of vibration system B by that of since the drop volume q decreases as mentioned above if c0 is made small.
[0097] As shown in a degree type, the acoustic capacitance c1 of a pressure room is proportional to the volume W1 of a pressure room. However, kappa is the bulk-modulus [Pa] of ink and alpha is a correction factor (0< alpha<1).
[0098]
[Formula 7]

$$c_1=\frac{W_1}{\kappa\cdot\alpha} \qquad (7)$$

[0099] In the ink jet recording head which carries out the regurgitation of drop volume of 15 or more pls, the minimum of the area of base of a pressure room is about 9x10 to 8 m2, and the minimum of pressure room height is set to about 50 micrometers, in order to secure the fluidity of ink. Therefore, the acoustic capacitance c1 of a pressure room serves as a value more than 2x10-20m5/N. Therefore, in order to control the vibration amplitude of vibration system B small, it is necessary to set up with c0 >=2x10-20m5/N. That is, it is c0 >=2x10-20[m5/N] also from the viewpoint of preventing the effect of vibration system B and obtaining the stable meniscus oscillation.
** -- it becomes important conditions.
[0100] Moreover, in order to reduce the effect vibration system B affects vibration system A, considering as TB<<Tc (conditions 2) is also important. That is, if the natural period TB of vibration system B can be set up sufficiently small compared with Tc, it will become possible to suppress the substantial effect on meniscus behavior small. The natural period TB of vibration system B needs to make cc and m0 small, in order to make TB small, since it is expressed with a formula (4).
[0101] In order to perform fluid simulation and normal expulsion of an ink droplet from the result of a actual regurgitation experiment, it became clear that being referred to as TB<Tc/10 is desirable. Therefore, it is necessary to set up m0 so that the conditions of a bottom type may be satisfied.
[0102]
[Formula 8]

$$m_0<\frac{1}{c_c}\left(\frac{T_c}{20\pi}\right)^2=2.53\times10^{-4}\frac{T_c^2}{c_c} \qquad (8)$$

[0103] As stated above, the point which showed clearly that it is what the shimmy of the meniscus shown in drawing 39 (b) depends on the effect of the 2nd vibration system (vibration system B) contained in a head, and clarified further the conditions which can control the adverse effect by vibration system B is also one of the descriptions of this invention. In addition, the example of disclosure which bent and made reference about existence of the above-mentioned vibration system B and its effect in the ink jet recording head using the deforming electrostrictive actuator does not exist, as far as this invention persons get to know.
[0104] As stated so far, from the "large drop regurgitation" and a viewpoint of "normalization (effect control of vibration system B) of a meniscus oscillation", it turned out that c0 is so advantageous that it is large. However, if c0 is enlarged on the other hand as shown in a formula (3), a natural period Tc will increase. As mentioned above, in order to carry out the regurgitation of the minute drop with a meniscus control system, it is necessary to hold down a natural period Tc to below fixed. It is necessary to specifically set Tc as 15 or less microseconds. It is there, next the upper limit of c0 is considered from a viewpoint of setting up a natural period Tc small.
[0105] As shown in a formula (3), Tc is proportional to an m2 and m3/(m2+m3) 1-/square. Inertance m is a parameter decided by duct cross-section A [m2] and duct die-length l [m] like a degree type. However, rho is the consistency [kg/m3] of ink.
[0106]
[Formula 9]

$$m=\frac{\rho l}{A} \qquad (9)$$

[0107] In a general ink jet recording head, the inertance m3 of a nozzle and the inertance m2 of a supply way are set up almost equally. Because, although the refill rate which is an ink supplement rate after the drop regurgitation as it is m3 >>m2 becomes large, regurgitation effectiveness will fall (see the formula 2). On the other hand, although regurgitation effectiveness increases that it is m3 <<m2, a refill rate will fall. Therefore, in a general ink jet recording head, in order to aim at coexistence with regurgitation effectiveness reservation and the increment in a refill rate, it is set up with m2**m3.
[0108] Moreover, if it thinks from the actual nozzle dimensions of 30 micrometers or less of opening, i.e., a diameter, die length of 20 micrometers or more, and the nozzle dimensions used as 15 degrees or less of taper angles, m3 will become a four or more 2x107 kg/m value. therefore, m2 and m3/(m2+m3) -- about -- 1x107 kg/m4 serves as a lower limit.
[0109] Moreover, as mentioned above, as for the acoustic capacitance c1 of a pressure room, abbreviation 2x10-20m5/N serves as a minimum. Therefore, in order to obtain the natural period Tc for 15 or less microseconds from a formula (3), it is necessary to set acoustic capacitance c0 below to 5.5x10-19m5/N. That is, like [natural period / Tc] the case of the drop volume q, although some determinants (parameter) exist, when it is going to set up Tc small, only c0 becomes a rule parameter substantially. And in order to obtain the natural period Tc for 15 or less microseconds suitable for the globule regurgitation, it becomes a requirement to set acoustic capacitance c0 below to 5.5x10-19m5/N.
[0110] In the ink jet recording head using the electrostrictive actuator which will bend and deform if the above content is summarized, if the drop volume q and a natural period Tc are governed by the acoustic capacitance c0 of an oscillating element and the upper limit/lower limit of other parameters are taken into consideration, the optimal range exists in c0. That is, the "large drop regurgitation" and the "globule regurgitation" can be reconciled by setting up acoustic capacitance c0 so that the conditions of a degree type may be satisfied.
2.0x10-20 <=c0 <=5.5x10-19 [m5/N] (10)
[0111] Moreover, by satisfying the conditions of c0>c1 and a formula (8), the effect of the 2nd vibration system (vibration system B) formed in a head can be controlled, and the ink jet recording head excellent in regurgitation stability and dependability can be realized. Furthermore, by setting the aspect ratio of a pressure room as abbreviation 1, c0 per unit area can be maximized and an ink jet recording head with a

high nozzle consistency can be realized.
[0112] With reference to a drawing, this invention is further explained to a detail based on the example of the 1st operation gestalt concerning this invention below the example of the 1st operation gestalt. The concrete configuration of the oscillating element which fills the conditions of c>=2.0x10-20m5/N with this example of an operation gestalt is investigated and made as an experiment, and it is shown as a result of having conducted the expulsion-of-an-ink-droplet experiment. Drawing 12 is a perspective view shown where the ink jet recording head of this example of an operation gestalt is developed.
[0113] The diaphragm 41 with which this ink jet recording head accomplishes a part of the ink pool plate 38, ink umbilical plate 39, pressure room plate 40 with which two or more pressure rooms 14 were formed, and wall surface of the pressure room 14 at the nozzle plate 29 top by which two or more nozzles 13 were formed in the shape of a matrix (letter of a matrix) is joined to this order. Two or more electrostrictive actuators 16 are joined to the diaphragm 41 so that each pressure room 14 may be countered.
[0114] Drawing 13 is a top view shown where a part of configuration of drawing 12 is seen through. The nozzle configuration of this example of an operation gestalt is considered as the array of the shape of a matrix of eight line x8 train. The nozzle pitch in a line writing direction is 42.3 micrometers corresponding to resolution 600dpi. Therefore, a row pitch is 42.3micrometerx8 train =338micrometer, and width of face in the line writing direction of the pressure room 14 is set to 328 micrometers settled in the pitch.
[0115] Moreover, a row pitch is also set to 338 micrometers and width of face in the direction of a train of the pressure room 14 is set to 328 micrometers settled in the pitch. That is, the flat-surface configuration of the pressure room 14 is a square. The flat-surface configuration of an oscillating element is also the same as the flat-surface configuration of the pressure room 14, and, as for the plane area, area is made small 0.108mm more nearly substantially than 2 and the conventional structure. When the flat-surface dimension of an oscillating element is decided, the structure parameter which determines acoustic capacitance is only the diaphragm 41, the construction material of an electrostrictive actuator 16, and thickness which are the configuration member. Here, the construction material of stainless steel (SUS304) and an electrostrictive actuator 16 was decided to be titanic-acid lead zirconate system ceramics for the construction material of a diaphragm 41. Therefore, the structure parameter which remains is the thickness of these two members.
[0116] In order to decide thickness, the relation between the thickness of two members and acoustic capacitance c0 was investigated first. For calculation of acoustic capacitance c0, excluded volume deltaV at the time of impressing the homogeneity pressure p to the structure-model-ized oscillating element using finite element analysis was calculated, and it considered as c0=deltaV/p.
[0117] What summarized the above-mentioned result is shown in the graph of drawing 14 . In a graph, the thickness of a diaphragm 41 is taken along an axis of abscissa, the thickness of an electrostrictive actuator 16 is taken along an axis of ordinate, analysis examination of the acoustic capacitance c0 to those combination is conducted, and it is c0 >=2.0x10-20[m5/N].
The field of the combination with which ****** is filled was smeared away and expressed. In every thickness combination in the field, the excluded volume of an oscillating element can obtain 15 or more pls. Therefore, in the ink jet recording head using this, the regurgitation of the ink droplet of 15 or more pls can be carried out.
[0118] In this example of an operation gestalt, the prototype which set thickness of 5 micrometers and an electrostrictive actuator 16 to 10 micrometers for the thickness of a diaphragm 41 was performed as one of the solution of the, and the expulsion-of-an-ink-droplet experiment was further conducted combining ink passage. The example is shown below.
[0119] That is, the whole of the dimension of a nozzle plate 29, the ink pool plate 38, the supply way plate 39, the pressure room plate 40, and a diaphragm 41 is the same, and width of face in the direction in which 4mm, a head scanning direction, and the width of face in a head scanning direction cross at right angles is set to 4mm. Moreover, also let all construction material be stainless steel (SUS304).
[0120] By press working of sheet metal, thickness is 50 micrometers, and a nozzle plate 29 follows an

above-mentioned layout, and is penetrated, and the nozzle 13 of the shape of a matrix with a diameter of 25 micrometers is formed. The thickness of the ink pool plate 38 is 200 micrometers, with a diameter of 28 micrometers which is open for free passage for nozzle 13 free passage hole 38a is formed by press working of sheet metal, and ink pool 38b is formed by etching processing.
[0121] With a diameter of 25 micrometers to which thickness opens supply way plate 39 for free passage to with a diameter of 28 micrometers which is 50 micrometers and is open for free passage for nozzle 13 with press working of sheet metal free passage hole 39a, and ink pool 38b ink supply way 39b is formed. Thickness is 80 micrometers, according to the above-mentioned flat-surface configuration, it is etching processing and, as for the pressure room plate 40, two or more pressure rooms 14 are formed. As already stated, thickness is set to 5 micrometers, and a diaphragm 41 has conductivity, and functions also as a common electrode for impressing the driver voltage wave of an electrostrictive actuator 16. The alignment marker (not shown) for carrying out positioning junction is mutually given to five kinds of above plates.
[0122] Thickness is set to 10 micrometers as the electrostrictive actuator 16 was already described. Each electrostrictive actuator 16 is formed according to the individual on the diaphragm 41 corresponding to each pressure room 14, and that of the flat-surface configuration is the same as that of the appearance of the pressure room 14.
[0123] The electrode layer is formed in both sides of an electrostrictive actuator 16, respectively. The flexible cable (not shown) which has an electric circuit pattern, and the electrode layer by the side of the free surface of an electrostrictive actuator 16 (individual electrode) are electrically connected through wirebonding.
[0124] Next, the manufacture approach of the ink jet recording head of this example of an operation gestalt is explained. Drawing 15 is the perspective view showing this manufacture approach, and (a) - (d) shows each process gradually. First, as shown in drawing 15 (a), lap polish processing is performed to a cylinder-like block [piezoelectric-material] (not shown), and the piezoelectric-material plate 42 is produced. Polish processing is performed so that thickness may become the same as the design thickness of an electrostrictive actuator 16. An electrode layer 43 is formed in both sides of this piezoelectric-material plate 42 by sputtering, respectively. In this example of an operation gestalt, gold (Au) was used as an electrode material of an electrode layer 43.
[0125] Subsequently, as shown in drawing 15 (b), temporary immobilization of the piezoelectric-material plate [finishing / sputtering] 42 is carried out at a stationary plate 45 through the adhesion foaming tape 44 which has the property whose adhesion is lost at the time of an elevated temperature. The alignment marker (not shown) for performing junction positioning with a nozzle plate 29, the pressure room plate 40, and the SUS plate of diaphragm 41 grade is prepared in this stationary plate 45.
[0126] Furthermore, as shown in drawing 15 (c), the film mask 46 which has photosensitivity is stuck on the piezoelectric-material plate 42 which carried out temporary immobilization. In this example of an operation gestalt, the urethane system film mask with a thickness of 10 micrometers is used as a film mask 46. Then, the exposure mask 47 formed in the pattern which makes only the part which it leaves as an electrostrictive actuator 16 penetrate ultraviolet rays (UV) is prepared separately. Patterning of this film mask 46 is carried out on the basis of the alignment marker of a stationary plate 45.
[0127] Then, UV exposure is performed on the piezoelectric-material plate 42 covered with the film mask 46 using the exposure mask 47, and it etches into the film mask 46 further. What has the property that the part to which the UV irradiation of the film mask 46 was carried out is not removed, but the other part can be removed certainly is chosen as an etching reagent. The sodium-carbonate solution was used in this example of an operation gestalt.
[0128] The film mask 46 is covered with the process to the above only into a part to leave as an electrostrictive actuator 16, and the film mask 46 is removed from the other part. Then, sandblasting processing is performed to this structure. This sandblasting processing is performed under conditions which carry out grinding clearance of the piezoelectric-material plate 42 of a part which the film mask 46 was removed and was exposed certainly, and do not carry out grinding of the part in which the film mask 46 remained.

[0129] Then, the film mask 46 which remained on the front face of the piezoelectric-material plate 42 is removed and washed. According to the above process, as shown in drawing 15 (d), both sides can be equipped with an electrode layer 31, and the piezoelectric material of the structure which stuck the wafer-ized electrostrictive actuator 16 on the adhesion foaming tape 44 on the stationary plate 45 can be obtained.

[0130] Subsequently, the process which sticks the above-mentioned piezoelectric material on a diaphragm 41 is performed. First, adhesives (not shown) are applied to the front face of the piezoelectric material shown in drawing 15 (d). In this example of an operation gestalt, since a diaphragm 41 is made to serve a double purpose as a common electrode, the adhesives which have conductivity are used for the adhesives to apply. After applying this, superposition and 2kg [per square centimeter] application of pressure are performed for piezoelectric material and a diaphragm 41 by making the alignment marker of a diaphragm 41 and a stationary plate 45 into positioning criteria, adhesives thermosetting in the bottom of the temperature of 200 degrees C are stiffened, and both sides are joined. In addition, since the adhesion foaming tape 44 used in order to carry out temporary immobilization of piezoelectric material and the stationary plate 45 at the time of this heating loses adhesion with heat, it exfoliates easily.

[0131] According to the above process, it has the electrostrictive actuator 16 wafer-ized on Perilla frutescens (L.) Britton var. crispa (Thunb.) Decne. as the common electrode in the diaphragm 41, and the unit with which the individual electrode was prepared on each electrostrictive actuator 16 is obtained. This unit is pasted up and joined with the plate unit which is the junction article of nozzle plates 29 other than diaphragm 41 joined [which joined and positioning-pasted up] separately, the ink pool plate 38, the supply way plate 39, and the pressure room plate 40. Thereby, an ink jet recording head can be obtained.

[0132] Finally, electrical connection for impressing a driver voltage wave to each electrostrictive actuator 16 is performed. In this example of an operation gestalt, the FPC cable (not shown) was stuck on the periphery of an ink jet recording head, and the electrode terminal and individual electrode of each electrostrictive actuator 16 were connected by wirebonding.

[0133] Next, actuation of this example of an operation gestalt is explained. That is, each pressure room 14 is filled up with ink via ink pool 38b to ink supply way 39b shown in drawing 12 to the ink jet recording head made as an experiment as mentioned above. Then, if driver voltage is impressed between the individual electrode of each electrostrictive actuator 16, and a diaphragm 41 (common electrode), the oscillating element which consists of a diaphragm 41 and an electrostrictive actuator 16 will bend, it will deform, and an ink droplet will carry out the regurgitation from the corresponding nozzle 13 by compressing the ink with which it filled up in the pressure room 14.

[0134] The regurgitation experiment of an ink droplet was conducted using the above ink jet recording head. Drawing 16 is a graph which shows the driver voltage wave used in this experiment. In the graph, an electrical potential difference [V] is taken along an axis of ordinate, and time amount [mus] is taken along the axis of abscissa.

[0135] First, the driver voltage wave shown in drawing 16 is inputted into each oscillating element according to an individual. Consequently, it checked that the ink droplet of 20pl(s) stabilized and carried out the regurgitation from each nozzle 13. Furthermore, the number of the oscillating elements driven simultaneously was changed, and the same experiment was conducted. Consequently, it checked that it was stabilized and the regurgitation of the ink droplet of the same drop measure could be carried out irrespective of the number to drive. Moreover, the difference in the regurgitation property (whenever [regurgitation drop volume and regurgitation drop speed], discharge direction) by the location to drive was not checked, either.

[0136] In the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.2x10-20m5/N by structural analysis and location survey assessment by the finite element method. That is, the ink jet recording head of this example of an operation gestalt is c0 >=2.0x10-20[m5/N].

****** is filled.

[0137] that is, the thing which the large drop regurgitation of 15 or more pls will become possible if the conditions of c0 >=2.0x10-20m5/N are fulfilled -- the experimental result of this example of an operation gestalt -- it was checked.
[0138] Example drawing 17 of the 2nd operation gestalt is the perspective view which developed the ink jet recording head of this example of an operation gestalt. In this ink jet recording head, ink passage is formed by carrying out laminating junction of a total of a nozzle plate 1, the common passage plate 2, the supply way plate 4, the pressure room plate 5, and the five plates of a diaphragm 6 with adhesives.
[0139] Common passage is constituted by one mainstream way 7 and 26 branching passage (five are displayed in drawing 17) 8. The mainstream way 7 is open for free passage on the ink tank (not shown) through a feed hopper 9, and has the function which supplies ink to each branching passage. Every ten pressure rooms 14 are connected with each branching passage 8, respectively (five pieces are displayed in drawing 17). That is, the ink jet recording head of this example of an operation gestalt is constituted as a matrix-like array head which has 260 ejectors.
[0140] Drawing 18 is drawing having shown the cross section of one ejector. The pressure room 12 is connected with the branching passage 8 through the ink feed holes 11, and it fills up with ink in the pressure room 12. The nozzle 10 for carrying out the regurgitation of the ink droplet is connected with each pressure room 12. Moreover, the diaphragm 6 is formed in the base of the pressure room 12, and the electrostrictive actuator 27 is attached in the diaphragm 6. When a driver voltage wave is impressed to this electrostrictive actuator 27, an electrostrictive actuator 27 bends and deforms and makes the pressure room 12 expand or compress. If a volume change arises in the pressure room 12, a pressure wave will occur in the pressure room 12. The ink of the nozzle section exercises, it is discharged by operation of this pressure wave from a nozzle 10 outside, and an ink droplet is formed of it. In addition, 24 shows a free passage way.
[0141] In this example of an operation gestalt, the polyimide film with a thickness of 25 micrometers was used for the nozzle plate 1, and the nozzle 10 of 25 micrometers of diameters of opening was formed by excimer laser processing. If a resin film is used for the member (nozzle plate 1) which forms a nozzle like this example of an operation gestalt, a nozzle plate 1 can be operated as an air damper of the branching passage 8, and the regurgitation stability at the time of the multi-nozzle simultaneous regurgitation can be raised. That is, in head structure as shown in drawing 18 , if the nozzle plate in which a nozzle 10 is formed is formed with a resin film, a part of wall surface (top face) of the branching passage 8 will serve as a resin film. If the wall surface of branching passage is constituted from a rigid low resin film, the acoustic capacitance of branching passage can increase substantially, generating of the sound wave propagation (cross talk) through branching passage etc. can be prevented, and the regurgitation stability at the time of the multi-nozzle simultaneous regurgitation can be raised. In addition, in order to secure sufficient acoustic capacitance for branching passage and to give the functions (cellular contamination prevention on a discharge direction disposition etc.) as a nozzle to the nozzle section, it is suitable for the thickness of a resin film that it is within the limits of 20-70 micrometers. However, even if it is except this optimum range, it is possible to acquire the same operation effectiveness with imperfection. The ink feed holes 11 of 26 micrometers of diameters of opening were formed in the supply way plate 4 with a press using the stainless plate with a thickness of 75 micrometers.
[0142] The passage pattern was formed in the common passage plate 2 and the pressure room plate 5 by wet etching using the stainless plate with a thickness of 100 micrometers. Die length of one side used the pressure room 12 as the square of 500 micrometers and an aspect ratio 1, and as shown in drawing 19 (a), in order to prevent the stagnation of ink flow, it gave R configuration to the corner of the pressure room 12. The stainless plate (Ev=197GPa) with a thickness of 10 micrometers was used for the diaphragm 6. Px in drawing 19 (a) shows the nozzle pitch of a main scanning direction 428 (refer to drawing 42), and Py shows the nozzle pitch of the direction 429 of vertical scanning, respectively.
[0143] Drawing 19 (b) is drawing having shown the configuration of the electrostrictive actuator 27 used in this example of an operation gestalt. Veneer-like piezo-electricity ceramics (titanic-acid lead zirconate system ceramics) (Ep=200GPa) with a thickness of 30 micrometers was used for the

electrostrictive actuator 27. Width of face Wp of an electrostrictive actuator was set to 490 micrometers almost equal to the pressure room width of face W, and used the sandblasting processing method for processing. In addition, 37 shows the electrode pad section and 38 shows an actuator, respectively.
[0144] As a result of structural analysis and location survey assessment by the finite element method, by the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.2x10-20m5/N, and the inertance m0 was called for with 1.3x106 kg/m4. Moreover, the acoustic capacitance of the pressure room 12 was 2.0x10-20m5/N (cc=1.2x10-20m5/N). That is, the ink jet recording head of this example of an operation gestalt fulfills the conditions of a formula (8) and a formula (10).
[0145] The driver voltage wave used for drawing 40 in this example of an operation gestalt is shown. drawing 40 -- (-- c --) -- being shown -- a large -- a drop -- ** -- driver voltage -- a wave -- comparatively -- being loose -- starting -- time amount -- a pressure -- a room -- compressing -- a sake -- the -- one -- an electrical potential difference -- change -- a process -- 402 -- " -- and -- fixed -- a period -- an electrical potential difference -- having held -- after -- applied voltage -- reference voltage (offset voltage Vb) -- returning -- a sake -- the -- two -- an electrical potential difference -- change -- a process -- 404 -- " -- constituting -- having -- **** . If this driver voltage wave is impressed to an electrostrictive actuator, a big pressure will occur in the pressure interior of a room to the timing to which 1st electrical-potential-difference change process 402" was impressed, and the ink in a nozzle will be injected towards the recording paper. It was set as section t7 "=15microsecond and electrical-potential-difference variation V2" =30V and bias voltage Vb=20V section t3 "=5microsecond and section t4" =10microsecond, respectively.
[0146] On the other hand, the driver voltage wave for globules shown in drawing 40 (a) is constituted by the 4th electrical-potential-difference change process 404 for returning the 3rd electrical-potential-difference change process 403 for expanding the 2nd electrical-potential-difference change process 402 for compressing the 1st electrical-potential-difference change process 401 for expanding a pressure room just before the regurgitation, and a pressure room at a rapid rate, and a pressure room at a rapid rate, and applied voltage to reference voltage. If this driver voltage wave is impressed to an electrostrictive actuator, the meniscus of nozzle opening will once be drawn in a pressure generating room side by the 1st electrical-potential-difference change process 401, and will form the meniscus of a concave configuration according to it.
[0147] Then, if the 2nd electrical-potential-difference change process 402 is added, a thin liquid column will be formed in a nozzle center section, and when a liquid column is further divided at an early stage by the 3rd electrical-potential-difference change process 403, an ink droplet smaller than the diameter of a nozzle will be breathed out. That is, this driver voltage wave is an actuation wave for carrying out the regurgitation of the minute drop with a meniscus control system. It was set as electrical-potential-difference variation V1=15V, electrical-potential-difference variation V2=12V, electrical-potential-difference variation V3=17V, and bias voltage Vb=20V, respectively section t1=2microsecond, section t2=2microsecond, section t3=2microsecond, section t4=0.5microsecond, section t5=2microsecond, section t6=5microsecond, and section t7=15microsecond.
[0148] drawing 40 -- (-- b --) -- being shown -- inside -- a drop -- ** -- driver voltage -- a wave -- a globule -- the same -- a meniscus -- control -- having used -- a thing -- it is -- the regurgitation -- just before -- a pressure -- a room -- expanding -- making -- a sake -- the -- one -- an electrical potential difference -- change -- a process -- 401 -- ' -- a pressure -- a room -- being rapid -- a rate -- compressing -- a sake -- the -- two -- an electrical potential difference -- change -- a process -- 402 -- ' -- and -- applied voltage -- reference voltage -- returning -- a sake -- the -- three -- an electrical potential difference -- change -- a process -- 404 -- ' -- constituting -- having -- **** -- . Like the 3rd electrical-potential-difference change process 403 of the driver voltage wave for globules, in early fragmentation of a liquid column, in order to hold a fixed period electrical potential difference after ******** and 2nd electrical-potential-difference change process 402', a bigger ink droplet a little than a globule is breathed out. It was set as electrical-potential-difference variation V1'=15V, electrical-potential-difference variation V2'=20V, and bias voltage Vb=20V, respectively section t1'=2microsecond, section t2'=2microsecond,

section t3'=2microsecond, section t4'=10microsecond, and section t7=15microsecond.
[0149] In addition, the actuation wave shown in drawing 40 is an example which shows the actuation approach of the ink jet recording head of this invention, and can also use the actuation wave of other configurations. That is, as long as it includes at least the 1st electrical-potential-difference change process of impressing an electrical potential difference in the direction which shrinks the volume of a pressure room as a wave for large drop regurgitation, and making an ink droplet breathing out, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which expands the volume of said pressure room, the actuation wave of a different configuration from drawing 40 (c) may be used.
[0150] For example, the electrical-potential-difference change process for drawing a meniscus in the interior of a nozzle slightly may be added just before 1st electrical-potential-difference change process 402", or another electrical-potential-difference change process may be added after 2nd electrical-potential-difference change process 404." As long as it includes at least the 1st electrical-potential-difference change process of similarly impressing an electrical potential difference in the direction which expands the volume of said pressure room as a wave for globule regurgitation, and the 2nd electrical-potential-difference change process of impressing an electrical potential difference in the direction which compresses the volume of said pressure room, the actuation wave of a different configuration from drawing 40 (a) may be used. For example, it may consider as the actuation wave which does not have the 3rd electrical-potential-difference change process 403 and the 4th electrical-potential-difference change process 404, or another electrical-potential-difference change process for controlling the initial state of a meniscus may be added just before the 1st electrical-potential-difference change process 401.
[0151] Drawing 41 is drawing having shown the basic configuration of the actuation circuit used in this example of an operation gestalt. In case image recording by the drop diameter modulation technique is performed, it impresses changing the driver voltage wave shown in drawing 40 for every pressure room to the electrostrictive actuator corresponding to each pressure room, and the drop diameter of the ink droplet made to breathe out is changed. In this example of an operation gestalt, in order to generate three sorts of driver voltage waves shown in drawing 40 (a) - (c), it has three kinds of wave generating circuits 411, 411', and 411", and each wave is amplified by an amplifying circuit 412, 412', and 412." Based on image data, at the time of record, an electrostrictive actuator 414, 414', and the driver voltage wave impressed to 414" are changed by a switching circuit 413, 413', and 413", and the ink droplet of a request drop diameter is breathed out at it.
[0152] The regurgitation experiment of an ink droplet was conducted using the ink jet recording head of this example of an operation gestalt described above. As a result of impressing the actuation wave (V1"=30V) shown in drawing 40 (c) to an electrostrictive actuator 27, it was checked that the ink droplet of drop volume 20pl is stabilized, and is breathed out from each nozzle 10. That is, it has checked experimentally that the regurgitation of the large drop exceeding 15pl becomes possible by using the electrostrictive actuator 27 which fulfills the conditions of acoustic capacitance c0 >=2.0x10-20m5/N. Moreover, refill time amount was also as brief as about 40 microseconds, and 18kHz high-speed actuation was possible for it.
[0153] As a result of performing image recording in the record paper using the ink jet recording head of this example of an operation gestalt, image concentration (OD value 1.3) sufficient also in the low record resolution of 600dpi was able to be obtained. That is, in the ink jet recording head of this example of an operation gestalt, since the large drop regurgitation of drop volume 20pl is possible, image concentration sufficient also in low record resolution called 600dpi can be obtained, and it can be said that it is an ink jet recording head very advantageous to high-speed record. In addition, when the applied voltage of an actuation wave was made to increase to V1"=40V, the drop volume of 27pl was obtained and image concentration (OD value 1.2) sufficient also in the record resolution of 300dpi was able to be obtained.
[0154] Drawing 21 is the result of observing a meniscus oscillation of the ink jet recording head of this example of an operation gestalt with a laser-doppler meter. It was checked that the natural period Tc of a

pressure wave is small stopped with 9.5 microseconds. That is, the natural period Tc for 15 or less microseconds suitable for the minute drop regurgitation was able to be obtained by using the oscillating element which fulfills the conditions of acoustic capacitance c0 <=5.5x10-19m5/N.
[0155] Moreover, in the ink jet recording head of this example of an operation gestalt, a fine oscillation was not able to be overlapped on a meniscus oscillation, but the very good meniscus oscillation was able to be obtained so that the meniscus oscillating wave of drawing 21 might show. The ink jet recording head of this example of an operation gestalt fulfills a formula (8) and the conditions of c0>c1, and this is because the amplitude of the vibration system B mentioned above is stopped small. Since such a stable oscillation was obtained by the meniscus, very high regurgitation stability was able to be acquired in the ink jet recording head of this example of an operation gestalt.
[0156] Moreover, when the globule regurgitation was performed by the actuation wave shown in drawing 40 (a), it was checked that the regurgitation of the minute ink droplet of drop volume 2pl can be carried out to stability. That is, in the ink jet recording head of this example of an operation gestalt, the natural period was as short as 9.5 microseconds, and since the shimmy of a meniscus was controlled, the minute drop regurgitation by the meniscus control system was able to be performed good. That is, in the ink jet recording head of this example of an operation gestalt, drop diameter modulation record was able to be performed in the large drop diameter range of 2-20pl by being impressed by each electrostrictive actuator, coexistence with the "large drop regurgitation" and the "globule regurgitation" being possible, and changing the driver voltage wave shown in drawing 40 according to an image pattern.
[0157] As an example of a comparison, thickness tp of an electrostrictive actuator, the thickness tv of a diaphragm, and the pressure room width of face W were changed, and same characterization was carried out. Consequently, as O plot of drawing 6 showed the drop volume, the structural-analysis result and the result which is in agreement with fitness were obtained. That is, although drop volume of 15 or more pls was obtained in the range of c0 >=2.0x10-20m5/N, on condition that c0<2.0x10-20m5/N, only drop volume of less than 15 pls was obtained, and sufficient image concentration was not able to be obtained. In addition, the conditions used as c0<2.0x10-20m5/N are combination, such as W= 500 micrometers, tv=10micrometer, tp=45micrometer, W= 400 micrometers, tv=5micrometer, and tp=35micrometer.
[0158] Although drop volume of 15 or more pls was obtained, the natural period Tc was set to 15 microseconds or more, and it became impossible moreover, to perform the globule regurgitation of 4 or less pls, when set to c0>5.5x10-19m5/N. The conditions used as c0>5.5x10-19m5/N are combination, such as W= 700 micrometers, tv=10micrometer, tp=15micrometer, W= 1000 micrometers, tv=10micrometer, and tp=35micrometer.
[0159] That a formula (10) is appropriate has checked experimentally as conditions for securing drop volume of 15 or more pls, and obtaining the natural period Tc for 15 or less microseconds from the above result. In addition, when an aspect ratio uses the pressure room of abbreviation 1, in order to set the acoustic capacitance of an oscillating element as the range of 2.0x10-20 <=c0 <=5.5x10-19 m5/N, it is desirable to set the thickness of 300-700 micrometers (plane area 0.09-0.5mm2), a diaphragm, and an electrostrictive actuator as the range of 5-20 micrometers and 15-40 micrometers for pressure room width of face, respectively.
[0160] Moreover, prototype assessment of a head was performed also about the rectangular pressure room whose aspect ratio is not abbreviation 1. Consequently, also at the rectangular pressure room, when fulfilling the conditions of a formula (10), it has checked that drop volume of 15 or more pls and the natural period for 15 or less microseconds were securable. However, although the same drop volume is obtained, one (the area of base of a pressure room) 2 to 5 times the actuation area of this is needed.
[0161] For example, in order to obtain the same drop volume (20pl) as the ink jet recording head of this example of an operation gestalt, in the ink jet recording head of an aspect ratio 5, 300x1500 micrometers of pressure room sizes needed to be set to 2. This is a twice [about] as many pressure room area as this as compared with the ink jet recording head of this example of an operation gestalt, therefore it means the array consistency of a nozzle falling to one half. That is, when fulfilling the conditions of a formula (10) also at the pressure room of a rectangle configuration, the target property was acquired, but in order to make it compatible with a high nozzle consistency, it was confirmed that it is optimal to set the aspect

ratio of a pressure room as abbreviation 1.
[0162] In addition, although the flat-surface configuration of an oscillating element can be made into an abbreviation equilateral triangle, an abbreviation square, or an approximate regular hexagon in the ink jet recording head of this example of an operation gestalt as mentioned above, as for these oscillating element, it is desirable to form a part for the joint of two sides each which adjoins mutually in the shape of a curve. That is, R configuration can be given to the corner (corner) of the pressure room 12 as shown in drawing 19 (a). This is for preventing that the stagnation point of ink occurs in the pressure interior of a room, and raising eccritic [of air bubbles].
[0163] That is, although the pressure wave which the pressure interior of a room was made to generate performs the regurgitation of an ink droplet in an ink jet recording head, if air bubbles remain in the pressure interior of a room, pressure generating effectiveness will fall, and the volume and drop speed of an ink droplet will decrease. The drop regurgitation may become impossible if residual air bubbles are large. So, in the usual ink jet recording device, cellular clearance of the pressure interior of a room is performed by attracting ink from a nozzle. However, since the stagnation point (part with the slow rate of flow) of ink occurs in the pressure interior of a room when the aspect ratio of a pressure room exists in 1 and an angle exists in near and a pressure room, cellular blowdown becomes difficult.
[0164] So, in the ink jet recording head of this example of an operation gestalt, by giving R configuration to the corner of a pressure room, generating of a stagnation point was prevented and it raised cellular eccritic one. as a result of investigate the cellular survival rate of the pressure interior of a room after actually perform ink attraction on certain conditions (ink be attract for 5 seconds by the pressure of 200mmHg(s) from a nozzle), when R configuration be gave, by the ink jet recording head of this example of an operation gestalt which added R configuration (curvilinear configuration), cellular survival be checked to the cellular survival rate having be 0 at 15 % of pressure room.
[0165] In the ink jet recording head of this example of an operation gestalt, since the high density array of many pressure rooms and electrostrictive actuators is carried out at the shape of a matrix, it becomes very difficult to perform electrical connection to each electrostrictive actuator. That is, as shown in drawing 35 , when the pressure room is arranged in one dimension, or when the high density array of many pressure rooms is carried out two-dimensional like this example of an operation gestalt although it is possible like the example of the 1st operation gestalt to perform electrical connection easily by the conventional electrical connection approaches (wirebonding etc.) when the number of pressure rooms also has little two-dimensional array, it is impossible to apply the conventional electrical connection approach.
[0166] So, in this example of an operation gestalt, the electrical connection approach as shown in drawing 22 and drawing 23 was used. That is, as the electrode pad section 37 (refer to drawing 19 (b)) was formed in an electrostrictive actuator and it was shown in drawing 22 , the electrical potential difference was impressed to each electrostrictive actuator by carrying out electrical connection of this electrode pad section and the wiring substrate (FPC substrate) 311 through a solder bump. Hereafter, it explains in more detail about the electrical connection approach of this example of an operation gestalt.
[0167] Drawing 22 (a) and (b) are the sectional view where the perspective view of before electric junction / back, drawing 23 (a), and (b) met the A-A line of drawing 22 (a), respectively, and the sectional view which met the B-B line of drawing 22 (b). The electrode 321 for common signals and the electrode 322 for individual signals are formed in the 2nd page which the electrostrictive actuator 312 arranged in the shape of a matrix counters, respectively, and the electrode 321 for common signals is joined to the conductive diaphragm 313 electrically and mechanically. The electrode 321 for common signals made the two-layer structure of Cr (0.2 micrometers) and Au (0.2 micrometers), and the electrode 322 for individual signals three layer systems of Cr (0.2 micrometers), and nickel (0.6 micrometers) and Au (0.2 micrometers).
[0168] The flexible-printed-wiring substrate (FPC substrate) 311 with which the individual signal line (signal line) was formed consists of three layers, the base film 323 which consists of resin material, the circuit pattern 324 which consists of a metallic conductor, and the covering layer 325. Moreover, the electrode 327 for individual signals is formed in the electrode pad section 326 of an electrostrictive

actuator, and a corresponding location, and the bump 330 of the shape of a semi-sphere which consists of conductive core material 328 and conductive jointing materials for corrugated fibreboard 329 is formed on this electrode 327. In this example of an operation gestalt, using Cu as core material 328, the pewter was formed in the front face of the core material 328 as a jointing material for corrugated fibreboard with electrolysis plating, and the bump was produced. At this example of an operation gestalt, it is phi150micrometer about a bump's path. Height was set as 60 micrometers.

[0169] At the time of electric junction, the FPC substrate 311 and an electrostrictive actuator 312 are made to counter mutually, where alignment is taken, application of pressure and heating are performed so that the location of the electrode pad section and a bump may be in agreement, and a bump 330 is joined for a jointing material for corrugated fibreboard to an electrode pad electrically and mechanically melting and by making it flow on an electrode pad. The pad 327 for electric junction on a diaphragm 313 and the FPC substrate 311 is electrically joined to the control circuit (not shown), and driver voltage is impressed to an electrostrictive actuator 312 through an individual signal line.

[0170] In the ink jet recording head of this example of an operation gestalt, the bump 330 is formed in the shape of a semi-sphere. This is for making the contact condition of the electrode pad section and a bump into homogeneity certainly. That is, even when gap arises in the parallelism of the FPC substrate 311 and an electrostrictive actuator 312, by what the bump is made hemispherical for, the contact condition of the electrode pad section and a bump 330 can be equalized, and while the stable electrical connection becomes possible, destruction of the electrostrictive actuator 312 at the time of electrical connection can be prevented.

[0171] Moreover, although the high FPC substrate 311 of flexibility is used for the wiring substrate in the ink jet recording head of this example of an operation gestalt, it is for this also securing positive contact between the electrode pad section and a bump 330. That is, if a wiring substrate is constituted from a low rigid-body ingredient of flexibility, it will be easy to generate poor contact between the electrode pad section and a bump 330 by the curvature of the passage plate to which the electrostrictive actuator was joined, or the variation of the thickness of an electrostrictive actuator selectively. On the other hand, if a wiring substrate is constituted from a high ingredient of flexibility, according to deformation of a wiring substrate, above-mentioned curvature and above-mentioned thickness dispersion can be absorbed, and uniform contact can be secured in all electrical connection parts.

[0172] Moreover, when the high ingredient of flexibility was used for the wiring substrate and an electrostrictive actuator 312 is driven, the stress generated between a bump 330 and the wiring substrate 311 can be reduced. That is, if an electrostrictive actuator 312 is driven, in order to also displace some electrode pad sections, the bump 330 on the electrode pad section also displaces together. If the rigid high substrate is used for the wiring substrate at this time, big stress will occur between each of the electrode pad section, a bump, and a wiring substrate, and producing fracture of an electrical connection etc. will become the cause of reducing the dependability of an electrical connection greatly. On the other hand, if the high ingredient of flexibility is used for a wiring substrate like this example of an operation gestalt, since a wiring substrate can be deformed according to a bump's variation rate, generating of stress can be controlled and it becomes possible to realize a reliable ink jet recording head.

[0173] Furthermore, the core material 328 is inserted in the interior of a bump 440 in the ink jet recording head of this example of an operation gestalt. Since it becomes possible to form a gap between an electrostrictive actuator 312 and the FPC substrate 311 after electrical connection by this, it becomes possible to bend freely and to deform, without an electrostrictive actuator 312 being restrained by the FPC substrate. That is, the poor property of the electrostrictive actuator 312 resulting from contact to an electrostrictive actuator 312 and the wiring substrate 311 can be prevented, and it becomes possible to realize a reliable ink jet recording head. Moreover, if a gap exists between an electrostrictive actuator 312 and the FPC substrate 311, it will become possible an air cooling without blower or to carry out forced-air cooling about the heat generated by actuation of an electrostrictive actuator 312, and it will also become possible to control change of the electrostrictive actuator property by the temperature rise.

[0174] By using the above electrical connection approaches, positive electrical connection can be made possible also to the electrostrictive actuator 312 by which the high density array was carried out two-

dimensional. That is, since the wiring substrate 311 is arranged above an electrostrictive actuator 312, the tooth space which arranges a signal line can be secured to the maximum, and it becomes possible to set up the array consistency of a nozzle highly as a result.
[0175] For example, since it is easy to form the circuit pattern of 50-micrometer pitch on the FPC substrate 311 when size arranges 500x500 micrometers of electrostrictive actuators 312 of 2 in the shape of a matrix by 10x10, the array pitch of an electrostrictive actuator 312 can be small set up to 575-micrometer pitch. This is a numeric value unrealizable by the conventional electrical connection approach in a matrix-like array head as shown in drawing 24 (a) and (b).
[0176] For example, with the conventional electrical connection technique which forms the individual signal line 335 in the same flat surface as an electrostrictive actuator 331, as shown in drawing 24 (b), since the minimum wiring pitch by screen-stencil is generally about 0.3mm, as for the array pitch of an electrostrictive actuator 331, about 3.6mm becomes a minimum. That is, the electrical connection approach like this example of an operation gestalt can be said to be a very effective approach when raising the nozzle consistency in a matrix-like array head. 333 in drawing and 336 show the wiring substrate, respectively.
[0177] Example drawing 25 of the 3rd operation gestalt (a) is the top view showing the head structure of this example of an operation gestalt. The ink jet recording head of this example of an operation gestalt has the description at the point of having set up smaller than the width of face W of the pressure room 242 the width of face Wp of an electrostrictive actuator 241, although basic structure is almost the same as the example of the 1st operation gestalt. That is, in case an electrostrictive actuator is joined on a diaphragm by setting up smaller than the pressure room width of face W the width of face Wp of an electrostrictive actuator 241, even if a location gap occurs, the acoustic capacitance c0 of an oscillating element can prevent changing sharply, and becomes possible [suppressing change of the drop volume and a natural period to min].
[0178] Drawing 26 is the result of investigating the change of which occurs in acoustic capacitance c0 with the width of face Wp of an electrostrictive actuator 241, when a center position gap of the pressure room 242 and the actuator 243 (part which bends actually and deforms) of an electrostrictive actuator 241 is set to delta [mum]. From this result, when setting up Wp so that the following conditions (formula (11)) might be satisfied, it became clear that change of the drop volume can be controlled small.
Wp<= (W-2delta) or -- Wp>= (W+2delta) (11)
[0179] The reason whose robustness (insensibility) over a location gap of an electrostrictive actuator improves under the above-mentioned conditions is because the support condition of an electrostrictive actuator edge becomes always fixed. That is, if electrostrictive actuator width of face is set up like drawing 25 (a) smaller than pressure room width of face so that the conditions of Wp<= (W-2delta) may be fulfilled, even if a location gap of **delta occurs, the actuator 243 of an electrostrictive actuator will not lap on the septum of the pressure room 242. Therefore, since the edge of an actuator 243 is always maintained as a revolution support condition, even if a location gap occurs, the ease of carrying out of deformation of an electrostrictive actuator does not change a lot, and acoustic capacitance c0 serves as an almost fixed value.
[0180] On the other hand, like drawing 25 (b), since the actuator 243 has lapped on the septum of the pressure room 242 even if a location gap occurs whenever it sets up electrostrictive actuator width of face more greatly than pressure room width of face so that the conditions of Wp>= (W+2delta) may be fulfilled, even if an actuator edge is always maintained as a fixed support condition and a location gap occurs, acoustic capacitance c0 does not change a lot.
[0181] As mentioned above, if the width of face Wp of an electrostrictive actuator 241 is set up so that the conditions of a formula (11) may be satisfied so that the support condition of an actuator edge may be kept constant even if a location gap occurs, fluctuation of the acoustic capacitance c0 by location gap can be suppressed to the minimum, and it will become possible to raise the robustness over a location gap.
[0182] However, if an actuator edge is made into a fixed support condition as Wp>= (W+2delta), since

deformation of an electrostrictive actuator will be restrained by the edge, as compared with the case of a revolution support condition, c0 decreases substantially. Moreover, also in Wp<= (W-2delta), if Wp is too small, regurgitation effectiveness will fall (since a substantial actuation area falls).
[0183] Drawing 27 is the result of investigating the relation between regurgitation effectiveness and variation (delta= 20 micrometers). In order to secure the robustness over a location gap and to acquire high regurgitation effectiveness from this result, it turned out that it is necessary to satisfy the following conditional expression.
0.9(W-2delta) <=Wp<= (W-2delta) (12)
[0184] In this example of an operation gestalt, since the amount delta of maximum location gaps generated at the time of junction of an electrostrictive actuator was 20 micrometers, Wp was set as 460 micrometers (the pressure room width of face W is 500 micrometers). That is, even if the **20-micrometer location gap occurred, it set up so that big effect might not occur in regurgitation effectiveness.
[0185] As a result of actually producing two or more recording heads and investigating dispersion in regurgitation effectiveness (ink droplet volume), it was checked that the difference of regurgitation effectiveness is settled to 5% or less between the heads which the delta= 20-micrometer location gap generated. Moreover, when evaluated by making a location gap increase to 30 micrometers or more intentionally, it was checked that 10% or more of difference occurs in regurgitation effectiveness. That is, it has checked that the robustness over a location gap could be improved by satisfying the conditions of a formula (12).
[0186] In addition, although it is dependent on the alignment approach at the time of junction of an electrostrictive actuator, the amount delta of location gaps of an electrostrictive actuator is set to about **10-**30 micrometers when the general alignment approach on the basis of an alignment mark is used. Therefore, as for the width of face Wp of an actuator, it is optimal to set up smaller pressure room width of face of about **10-**30 micrometers than W.
[0187] Moreover, it evaluated to the pressure room width of face W being 500 micrometers like drawing 25 (b) also about the electrostrictive actuator which set Wp as 540 micrometers. In this case, since the boundary condition of an actuator always serves as the fixed end even if a **20-micrometer location gap occurs, fluctuation of acoustic capacitance c0 can be controlled. As a result of investigating change of the drop volume by location gap, it was actually checked that the difference of regurgitation effectiveness is as small as 5% or less. However, since the boundary condition of an actuator is the fixed end, compared with the structure of drawing 25 (a), regurgitation effectiveness is 1/5 or less, and it can be told to the large drop regurgitation that it is disadvantageous structure.
[0188] In the ink jet recording head of this example of an operation gestalt, the acoustic capacitance c0 of an oscillating element was calculated with 3.5x10-20m5/N, and the inertance m0 was called for with 1.0x106 kg/m4. That is, the ink jet recording head of this example of an operation gestalt had also satisfied the conditions of a formula (8) and a formula (10), consequently drop volume 19pl (V1=30V) and 9.8 microseconds of natural periods were able to be obtained.
[0189] Example drawing 28 of the 4th operation gestalt is the top view showing the head structure of this example of an operation gestalt. The ink jet recording head of this example of an operation gestalt has the description in the point which constitutes the configuration of an electrostrictive actuator from an actuator 273, the electrode pad section 274, and the bridge section 275, although basic structure is the same as that of the example of the 3rd operation gestalt almost.
[0190] That is, it is separated into an actuator 273 and the electrode pad section 274 by formation of a through hole 278, and the electrostrictive actuator 271 is connected through the bridge section 275 in the part with the small variation rate of an actuator 273. Thereby, since the displacement constrain by the electrode pad section 274 of an electrostrictive actuator 271 is reduced, an ink jet recording head with high regurgitation effectiveness is realizable.
[0191] As expressed with the contour line 276 of drawing 28 , when the electrostrictive actuator 271 which an aspect ratio bends and deforms into the pressure room 272 near 1 is attached, an oscillating element deforms into the configuration near the spherical surface. Therefore, in the part which is more

distant from the core of the oscillating section, the amount of displacement becomes small. In the case of polygons (a square, hexagon, etc.), an electrostrictive actuator 271 serves as a part which is distant from a core with the field of the angle of the oscillating section 273. Therefore, electrical-potential-difference impression (electrical connection) to an actuator 273 can be enabled by connecting the bridge section 275 with the corner of the oscillating section 273 like this example of an operation gestalt, minimizing the displacement constrain of an electrostrictive actuator 271.
[0192] As a result of carrying out regurgitation assessment of the ink jet recording head of this example of an operation gestalt, compared with the structure of drawing 25 , regurgitation effectiveness was actually able to be increased by 20%. That is, the drop volume of 23pl(s) was able to be obtained by V1=30V. In addition, it is 3.7x10-20m5/N, an inertance m0 is 1.0x106 kg/m4, and, as for the acoustic capacitance c0 of an oscillating element, the ink jet recording head of this example of an operation gestalt is also satisfied with the ink jet recording head of this example of an operation gestalt of the conditions of a formula (8) and a formula (10).
[0193] Drawing 29 is the result of structural analysis and actual regurgitation assessment investigating the relation between the width of face Wb of the bridge section, and regurgitation effectiveness. The displacement-constrain force becomes small, so that the width of face of the bridge section is small, and the inclination which increases regurgitation effectiveness can be grasped. However, when width of face of the bridge section is made [too little], a crack occurs in the bridge section at the time of manufacture or an activity, and there is a possibility that it may become impossible to perform normal expulsion of an ink droplet. Therefore, as for the width of face Wb of the bridge section, it is desirable to set to the width of face Wp of an actuator to 1/2 or less and 1/4 or more.
[0194] The configuration of an electrostrictive actuator 271 can apply various configurations, as it is not limited to a configuration like drawing 28 and shown in drawing 30 (a) - (d). That is, as long as the bridge section 275 is connected with the part which is distant from the core of an actuator 273, the configuration of the bridge section 275 or the electrode pad section 274 may be what kind of configuration, and the number of the bridge section 275 may also be 1 or plural.
[0195] Moreover, like this example of an operation gestalt, it is advantageous to separate the actuator 273 and the electrode pad section 274 of an electrostrictive actuator 271, also when performing electrical connection of an electrostrictive actuator 271. That is, in the configuration of an electrostrictive actuator 241 as shown in drawing 25 , since an actuator 243 and the electrode pad section 244 are not separated, when the electrical connection approach which used the FPC substrate shown in drawing 22 and drawing 23 is used, the jointing material for corrugated fibreboard 329 shown in drawing 23 (a) and (b) flows into an actuator field, and there is a possibility that a jointing material for corrugated fibreboard may restrain deformation of an electrostrictive actuator. Since the distance of an actuator and the electrode pad section becomes short when the high density array of the pressure room 242 is carried out especially, it becomes easy to generate the problem of such a jointing-material-for-corrugated-fibreboard inflow.
[0196] On the other hand, like this example of an operation gestalt, if it is made the configuration where an actuator and the electrode pad section were separated, since the jointing-material-for-corrugated-fibreboard inflow to an actuator can be controlled effectively, it becomes possible to realize a reliable ink jet recording head.
[0197] In this example of an operation gestalt, the configuration of an electrostrictive actuator 271 turns into a complicated configuration as shown in drawing 28 and drawing 30 . So, sandblasting processing was used for processing of an electrostrictive actuator in this example of an operation gestalt. This becomes possible simple-wise about the electrostrictive actuator of a complicated configuration to process it into a precision for a short time, and to manufacture the ink jet of high density by low cost.
[0198] In the ink jet recording head of this example of an operation gestalt, as shown in drawing 28 , the dummy pattern 277 was arranged between the adjacent electrostrictive actuators 271. This is for preventing the effect of side etching generated at the time of sandblasting processing, and securing high dimension homogeneity to an electrostrictive actuator 271.
[0199] That is, if sandblasting processing of the electrostrictive actuator 271 is carried out, also

crosswise [of an electrostrictive actuator 271] in parallel to progress of processing (etching) to the thickness direction of an electrostrictive actuator 271, processing will advance (it is hereafter called side etching). In case sandblasting processing is performed, this side etching is generated in order that a blasting particle may collide also to the side face of a piezo-electric plate. And it depends for the working speed (processing rate) of this side etching on the width of face of the processing slot formed in a piezo-electric plate. That is, if the width of face of the processing slot formed in the side of an electrostrictive actuator 271 is large, side etching will tend to advance at a quick rate, and if the width of face of a processing slot is conversely small, it will be hard coming to generate side etching.
[0200] Thus, since the speed of advance of side etching changes with processing flute widths, if the processing flute width which encloses each electrostrictive actuator 271 is not fixed, variation will arise in the speed of advance of side etching, consequently the size of an electrostrictive actuator 271 will be irregular. In order for the size of an electrostrictive actuator 271 to affect a regurgitation property greatly, it is necessary to prevent the above uneven side etching.
[0201] Then, the dummy pattern 277 is formed also between the electrostrictive actuators 271 which adjoin mutually, and it was made for the width of face of the processing slot 279 which encloses each electrostrictive actuator 271 to be fixed (about 80 micrometers) mostly in the ink jet recording head of this example of an operation gestalt. By this configuration, all the electrostrictive actuators 271 could be processed on the same conditions, and the high electrostrictive actuator 271 of dimension homogeneity was able to be realized. Specifically, the precision of the width of face Wp of an electrostrictive actuator 271 was able to be suppressed to **5 micrometers or less. When sandblasting processing is carried out without forming the dummy pattern 277, it can be told to the width of face Wp of an electrostrictive actuator 277 that the effectiveness of forming the dummy pattern 277 as compared with dispersion **20 micrometers or more having occurred is very high.
[0202] Moreover, by the same reason as the above, as shown in drawing 31 , the dummy pattern 232 was arranged also in the periphery section of the field where two or more electrostrictive actuators 231 were arranged. That is, in the electrostrictive actuator 231 located in the periphery section of the field where many electrostrictive actuators 231 were arranged, since side etching occurs remarkably, it is hard to acquire especially the dimensional accuracy as an electrostrictive actuator. Therefore, it becomes possible to secure high dimension homogeneity also in the electrostrictive actuator 231 located in the periphery section by arranging dummy PAN 232 so that the arranged electrostrictive actuator group may be surrounded. In addition, the ink jet recording head of this example of an operation gestalt is available also as a gestalt which puts the subdivided dummy pattern in order, although the dummy pattern 232 of the periphery section was made into integral construction like drawing 31 .
[0203] As a result of applying the above-mentioned dummy pattern, in the ink jet recording head of this example of an operation gestalt, it became possible in 260 ejectors in a head to suppress dispersion in a regurgitation property (drop volume, drop speed) to **5% or less. Moreover, as a result of carrying out a property comparison among two or more recording heads, it was checked that the property variation between recording heads is also settled to **6% or less, and it was proved that the above-mentioned electrostrictive actuator structure using the dummy pattern 232 was very effective in equalization of a head property.
[0204] Example drawing 42 of the 5th operation gestalt is drawing showing the example of an operation gestalt of the ink jet recording device concerning this invention. The ink jet recording apparatus 420 of this example of an operation gestalt is constituted including the vertical-scanning device 423 for conveying the horizontal-scanning device 422 for scanning carriage 421 to the carriage 421 which carries an ink jet recording head, and the main scanning direction shown by the arrow head 428, and the record form 424 as a record medium in the direction of vertical scanning shown by the arrow head 429.
[0205] An ink jet recording head is carried on carriage 421 so that the field in which the nozzle was formed may counter with the record form 424, and it records to the fixed band field 427 by carrying out the regurgitation of the ink droplet to the record form 424, being conveyed in a main scanning direction 428. Subsequently, the next band field is recorded, conveying the record form 424 in the direction 429 of vertical scanning, and conveying carriage 421 to a main scanning direction 428 again. By repeating

such actuation two or more times, image recording can be performed over the whole surface of the record form 424.

[0206] Image recording was performed using the ink jet recording device of this example of an operation gestalt, and assessment of a recording rate and image quality was actually performed. The thing of the head structure stated in the above-mentioned example of the 4th operation gestalt was used for the ink jet recording head. Full color image recording was performed by making it correspond to four colors of yellow, a Magenta, cyanogen, and black, arranging the matrix-like array head which has 260 ejectors per color side by side on carriage 421, and piling up the dot of four colors on the record form 424.

[0207] As a result of recording by large drop volume 18pl, globule volume 2pl, and record resolution setting 600dpi and a regurgitation frequency as 18kHz, the image of A4 size (210mmx297mm) could be printed by the time amount for about 5 seconds, and it was proved that a very high recording rate was realizable. Moreover, since the globule volume was as small as 2pl(s), graininess was suppressed low and the highlights section was also able to realize very high image recording of drawing quality.

[0208] The same image output experiment was conducted using the conventional head of the number 64 piece / of nozzles, and color as an example of a comparison. Since 10pl(s) of the large drop volume in which the regurgitation is possible were upper limits, record resolution was set as 1200dpi. The globule volume set 6pl(s) and a regurgitation frequency as 18kHz, respectively. As a result of evaluating a recording rate, the time amount for about 85 seconds was taken to record the image of A4 size (210mmx297mm). Moreover, since the globule volume was as large as 6pl(s), graininess was conspicuous in the highlights section and image quality was low as compared with this example of an operation gestalt.

[0209] As mentioned above, in the ink jet recording device of this example of an operation gestalt, since the acoustic capacitance c0 of the oscillating element in a recording head is set as c0 >=2.0x10-20m5/N and the pressure room of a square mold with high regurgitation effectiveness is arranged in the shape of a matrix possible [the large drop regurgitation advantageous to a low resolution], the number of nozzles can be set up greatly. Therefore, it becomes possible to increase a recording rate substantially as compared with the conventional ink jet recording device. Moreover, in the ink jet recording device of this example of an operation gestalt, since the acoustic capacitance c0 of the oscillating element in a recording head is set as c0 <=5.5x10-19m5/N, the globule regurgitation by the meniscus control system can be performed good, and high image quality can be acquired. That is, it is possible for it to be compatible in high-speed record and high-definition record in the ink jet recording device of this example of an operation gestalt.

[0210] In addition, although considered as the gestalt which records while conveying a head with carriage 421 in this example of an operation gestalt, it is also possible to apply this invention to another equipment gestalt, such as to record fixing a head and conveying only a record medium using the line mold head which has arranged the nozzle covering full [of a record medium].

[0211] As mentioned above, although each example of an operation gestalt was explained, this invention is not limited to the configuration of the above-mentioned example of an operation gestalt. For example, although common passage and a pressure room are formed with the stainless plate in the above-mentioned example of an operation gestalt, the ceramics, glass, etc. are possible also for using other ingredients. Moreover, it is not limited to the gestalt shown in drawing 17 and drawing 18 , and the structure of the basic structure of a head, i.e., a nozzle, a supply way, and common passage, arrangement, etc. can also use other gestalten.

[0212] Moreover, in the above-mentioned example of an operation gestalt, although all the configurations of a pressure room were used as the square, even if it uses the configuration of other polygons (a triangle, a pentagon, hexagon, etc.) or an approximate circle form, the same effectiveness is acquired. Although the matrix-like array head was targetted for all the above-mentioned examples of an operation gestalt, this invention is applicable similarly to other head structures, such as head structure which arranged the pressure room in one dimension. Furthermore, in the above-mentioned example of an operation gestalt, although sandblasting processing was used for the processing approach (the

manufacture approach) of an electrostrictive actuator, other processing methods, such as dicing processing and the approach of forming piezoelectric material on a diaphragm by printing, can also be used. Moreover, a diaphragm and an electrostrictive actuator can also be cast as integral construction.
[0213] Moreover, although the ink jet recording apparatus which breathes out coloring ink in the record paper and records an alphabetic character, an image, etc. on it was taken for the example in the above-mentioned example of an operation gestalt, the ink jet record in this description is limited to neither the alphabetic character in the record paper, nor record of an image. That is, the liquid which a record medium is not necessarily limited to paper, and carries out the regurgitation is not necessarily limited to coloring ink, either. For example, the thing for which this invention is used to the general drop fuel injection equipment used industrially, such as breathing out coloring ink, producing the light filter for a display, or breathing out the pewter of a melting condition on a substrate and forming the bump for component mounting on a high polymer film or glass, is also possible.
[0214] If the flat-surface configuration where it used in this example of an operation gestalt sets to A the ratios d1/d2 of the path d1 of a circumscribed circle and the path d2 of an inscribed circle which touch a flat-surface configuration besides a square oscillating element, an oscillating element of a flat-surface configuration which fills 1<=A<=2 can be used. That is, although it is A=root2 (**1.4) with a square, it is [at A= 2 and a forward hexagon] A= 1 in an equilateral triangle in A=2/root3 (**1.2) and a perfect circle. Since the minimum width of face tends to bend greatly, even if the oscillating element which has these flat-surface configurations makes the plane area as small as possible, it can maintain excluded volume. Therefore, it becomes possible to low-cost[small and]-ize a head.
[0215] In addition, if the flat-surface configuration of an oscillating element, construction material, and thickness are the structures of it not being limited to what was made as an experiment in this example of an operation gestalt, and fulfilling the conditions of 2.0x10-20 <= acoustic capacitance c0 <=5.5x10-19 m5/N, even if they are other combination, they can acquire the effectiveness concerning this invention.
[0216] As mentioned above, although this invention explained based on the suitable example of an operation gestalt, the actuation approach of an ink-jet recording head is not limited only to the configuration of the above-mentioned example of an operation gestalt by the ink-jet recording head concerning this invention and its manufacture approach, an ink-jet recording apparatus, and the list, and the actuation approach of an ink-jet recording head is also included in the range of this invention in them at the ink-jet recording head which performed various corrections and modification from the configuration of the above-mentioned example of an operation gestalt and its manufacture approach, an ink-jet recording apparatus, and a list.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the sound circuit diagram of the oscillating element used for the ink jet recording head of the example of an operation gestalt concerning this invention.
[Drawing 2] It is drawing showing the equivalence electrical circuit of one ejector.
[Drawing 3] It is the graph which shows the relation between the excluded volume at the time of inputting a step pressure into an acoustic circuit, and a sound parameter, and, as for (a), excluded volume, acoustic capacitance, and (c) show the relation between excluded volume and acoustic resistance, respectively, as for excluded volume, an inertance, and (b).
[Drawing 4] It is drawing showing the relation between c0 and phi-c 0.
[Drawing 5] It is another graph which shows the relation between c0 and phi-c 0.
[Drawing 6] It is still more nearly another graph which shows the relation between c0 and phi-c 0.
[Drawing 7] It is drawing showing the effect of the aspect ratio of a pressure room.
[Drawing 8] It is drawing for explaining the definition of an aspect ratio.
[Drawing 9] It is drawing showing the frequency response of the equal circuit of drawing 2 (a).
[Drawing 10] It is drawing showing the equivalence electrical circuit of one ejector.
[Drawing 11] It is drawing for explaining the proper balance of the acoustic capacitance c0 of an oscillating element, and the acoustic capacitance c1 of a pressure room.
[Drawing 12] It is the perspective view shown where the ink jet recording head of the example of the 1st operation gestalt concerning this invention is developed.
[Drawing 13] It is the top view shown where a part of configuration of drawing 12 is seen through.
[Drawing 14] It is the graph which shows the relation between the thickness of a diaphragm and an electrostrictive actuator, and acoustic capacitance.
[Drawing 15] It is the perspective view showing the manufacture approach of the ink jet recording head of the example of the 1st operation gestalt, and (a) - (d) shows each process gradually.
[Drawing 16] It is the graph which shows the driver voltage wave used in the regurgitation experiment of an ink droplet.
[Drawing 17] It is the perspective view showing the plate configuration of the ink jet recording head of the example of the 2nd operation gestalt concerning this invention.
[Drawing 18] It is the sectional view of the ink jet recording head of the example of the 2nd operation gestalt.
[Drawing 19] It is drawing showing the flat-surface configuration of the ink jet recording head of the example of the 2nd operation gestalt.
[Drawing 20] It is drawing showing an example of an actuation wave for large drop regurgitation.
[Drawing 21] It is drawing showing a meniscus oscillation of the ink jet recording head of this invention.
[Drawing 22] It is drawing showing the electrical connection approach of the ink jet recording head of this invention.
[Drawing 23] It is the sectional view showing the electrical connection approach of the ink jet recording

head of this invention.
[Drawing 24] It is drawing showing the conventional electrical connection approach in a matrix-like array head.
[Drawing 25] It is drawing showing the flat-surface configuration of the electrostrictive actuator of the ink jet recording head of the example of the 3rd operation gestalt concerning this invention.
[Drawing 26] It is drawing showing the change of c0 by location gap of the electrostrictive actuator of the example of the 3rd operation gestalt.
[Drawing 27] It is drawing showing change of the regurgitation effectiveness by location gap of the electrostrictive actuator of the example of the 3rd operation gestalt, and drop volume dispersion.
[Drawing 28] It is drawing showing the flat-surface configuration of the electrostrictive actuator in the ink jet recording head of the example of the 4th operation gestalt concerning this invention.
[Drawing 29] It is drawing showing the bridge width of face of the example of the 4th operation gestalt, and the relation of regurgitation effectiveness.
[Drawing 30] It is drawing showing an example of the electrostrictive actuator configuration which can apply the example of the 4th operation gestalt.
[Drawing 31] It is drawing showing an example of the blasting pattern of the electrostrictive actuator in the ink jet recording head of the example of the 4th operation gestalt.
[Drawing 32] It is the 2nd mimetic diagram for explaining the behavior of the meniscus at the time of using a meniscus control system.
[Drawing 33] It is drawing showing the natural period of a pressure wave, and the relation of the minimum drop diameter in which the regurgitation is possible.
[Drawing 34] It is the sectional view showing the basic structure of the conventional ink jet recording head.
[Drawing 35] It is drawing showing the basic structure of a multi-nozzle mold ink jet recording head.
[Drawing 36] It is drawing showing the basic structure of the ink jet recording head of a matrix array type.
[Drawing 37] It is drawing showing an example of an actuation wave for globule regurgitation.
[Drawing 38] It is a mimetic diagram for explaining the behavior of the meniscus at the time of using a meniscus control system.
[Drawing 39] It is drawing showing an example (normal/abnormalities) of the observation of a meniscus oscillation.
[Drawing 40] It is drawing showing the driver voltage wave used in the example of an operation gestalt concerning this invention.
[Drawing 41] It is drawing showing the configuration of the actuation circuit used in the example of an operation gestalt concerning this invention.
[Drawing 42] It is drawing showing the example of 1 operation gestalt of the ink jet recording device concerning this invention.
[Description of Notations]
13: Nozzle
14: Pressure room
16: Electrostrictive actuator
29: Nozzle plate
38: Ink pool plate
38a: Free passage hole
38b: Ink pool
39: Ink umbilical plate
39a: Free passage hole
39b: Ink supply way
40: Pressure room plate
41: Diaphragm
42: Piezoelectric-material plate

43: Electrode layer
44: Adhesion foaming tape
45: Stationary plate
46: Film mask
47: Exposure mask

[Translation done.]

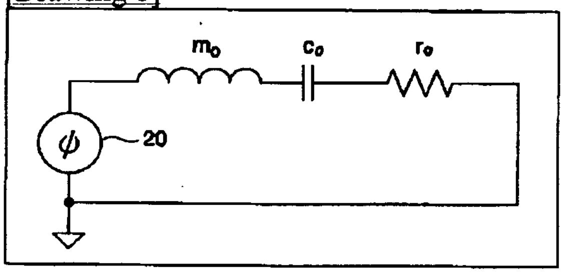
* NOTICES *

JPO and NCIPI are not responsible for any
damages caused by the use of this translation.

1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DRAWINGS

[Drawing 1]



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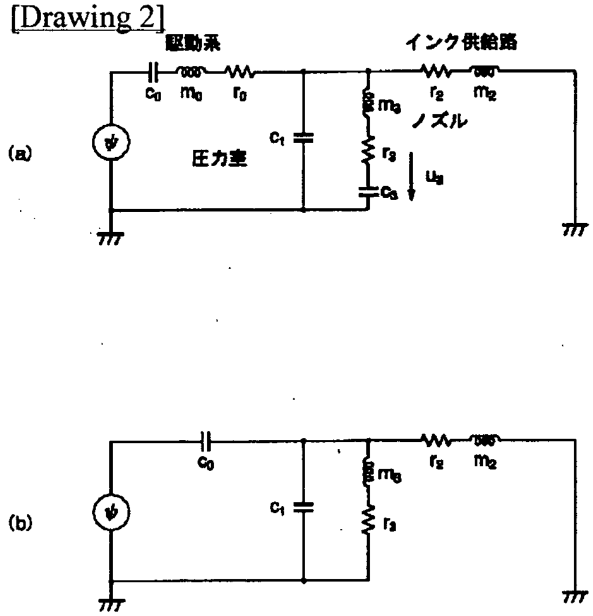
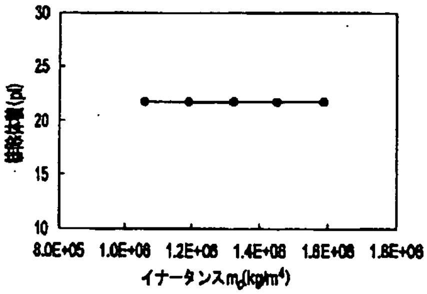


[Drawing 3]

(a)



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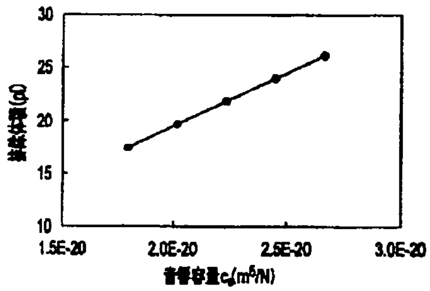

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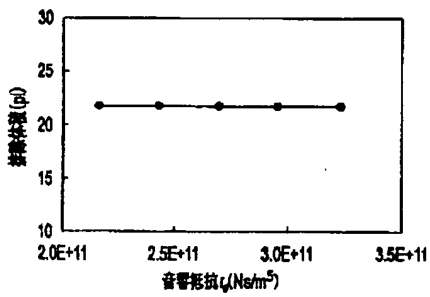

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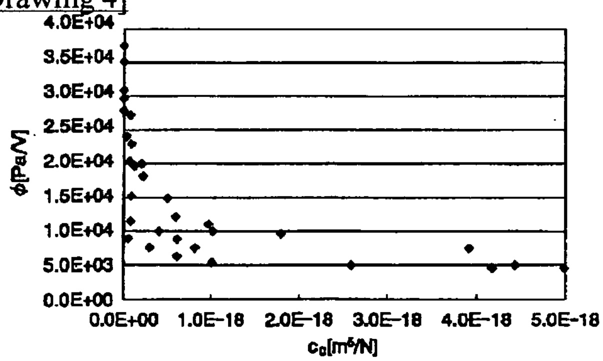

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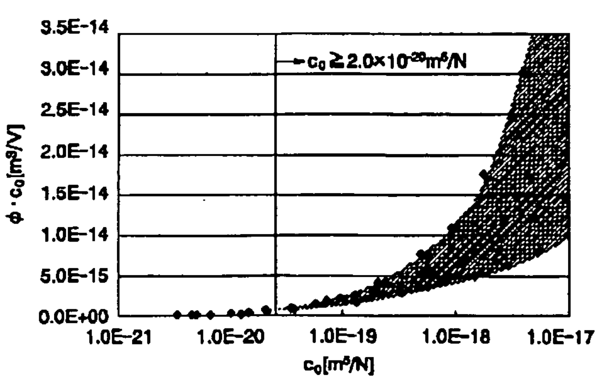

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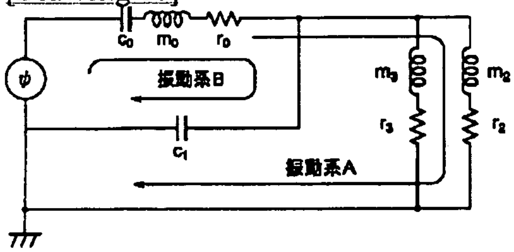

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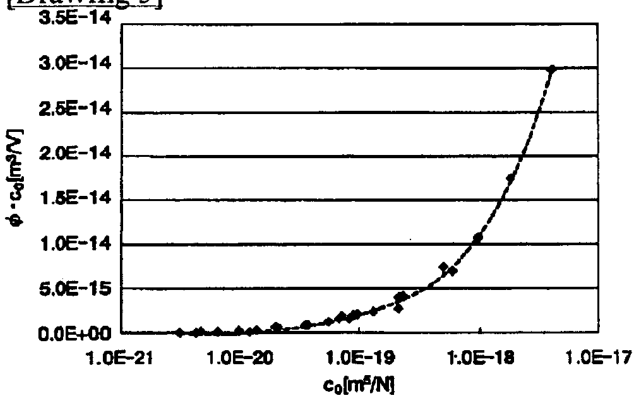

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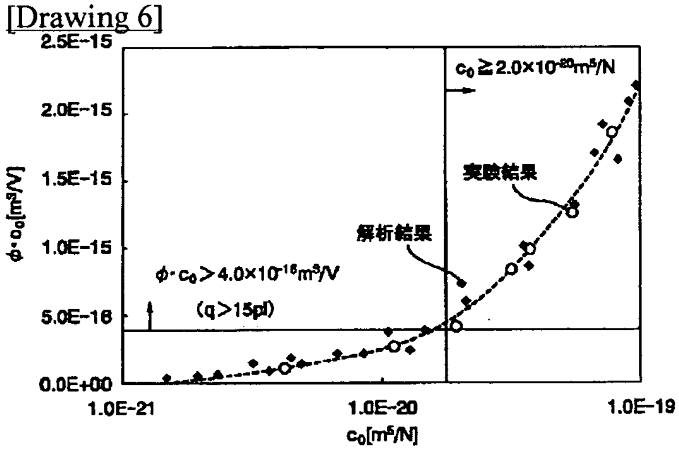

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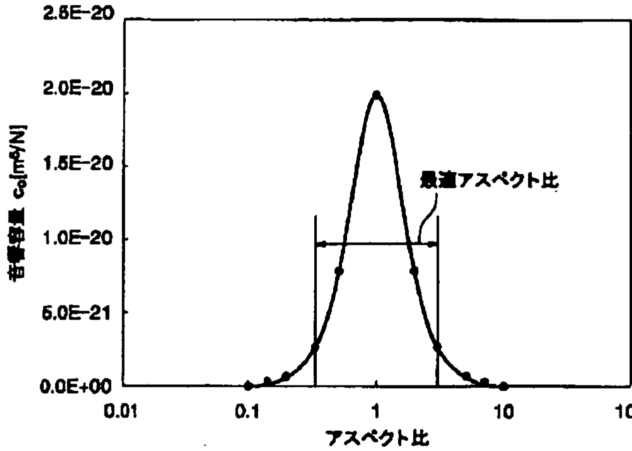

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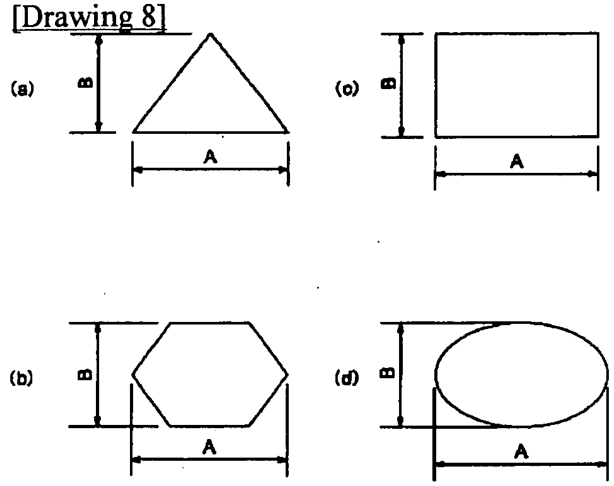

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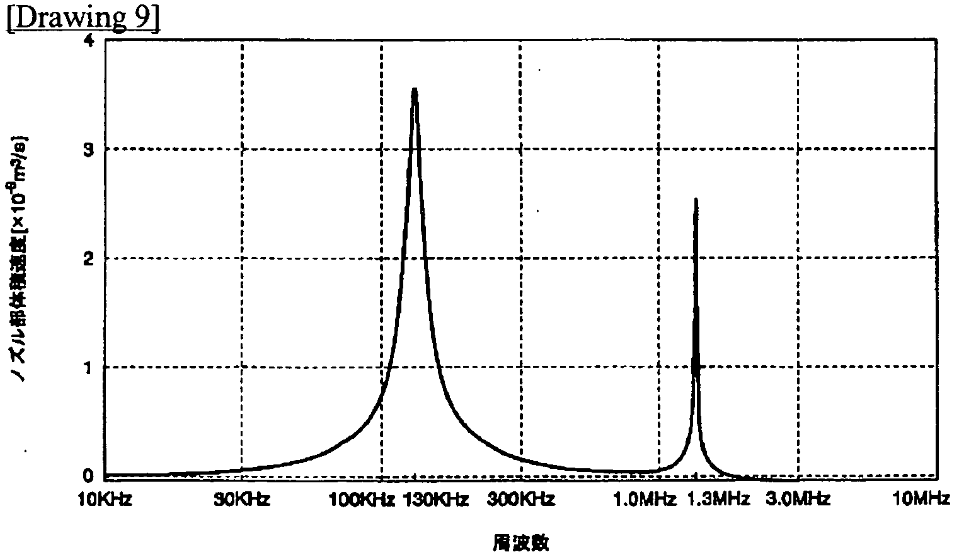

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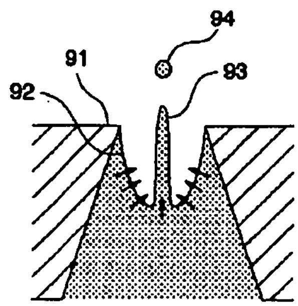

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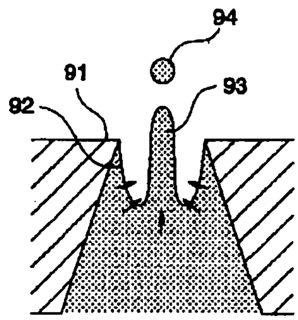

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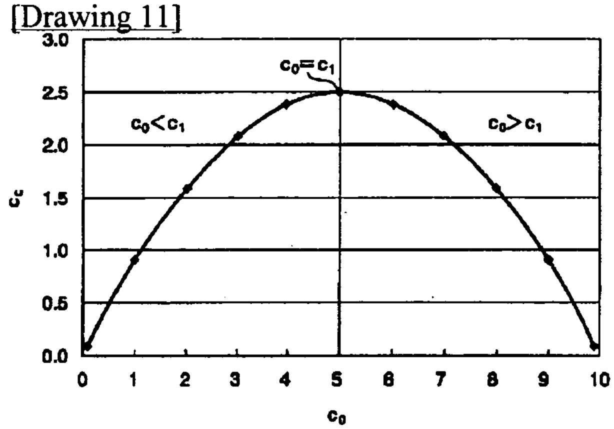

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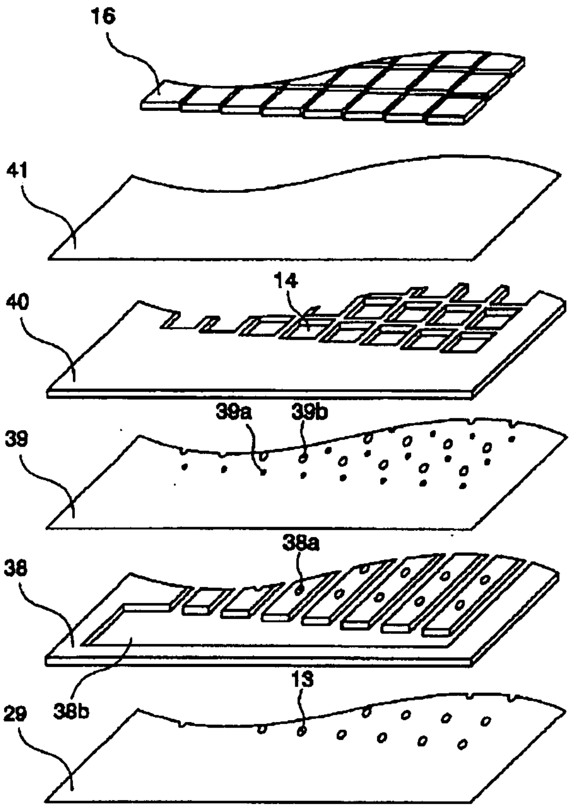

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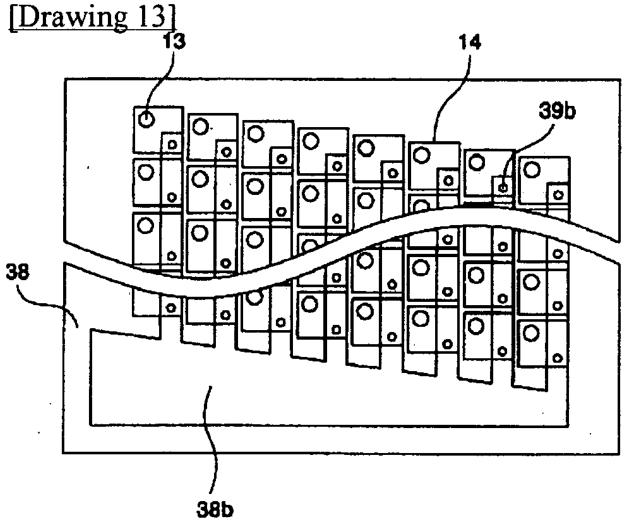

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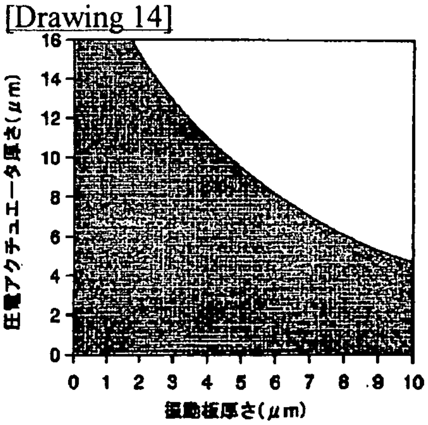

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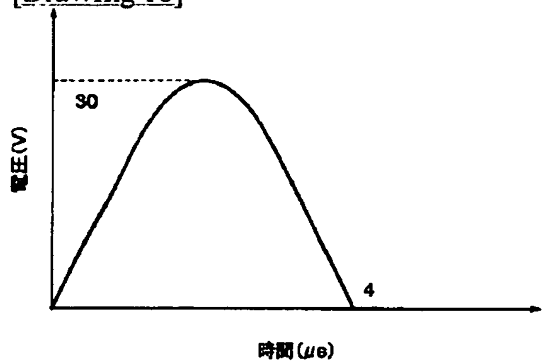

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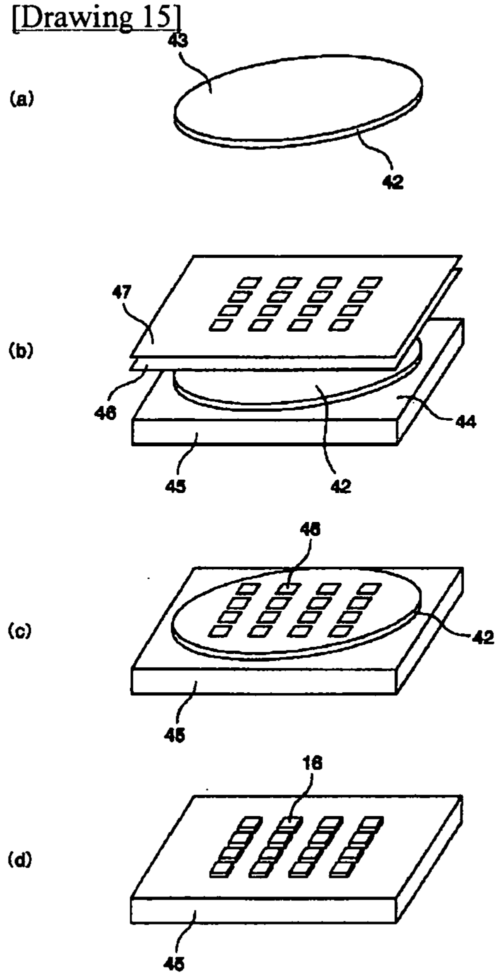

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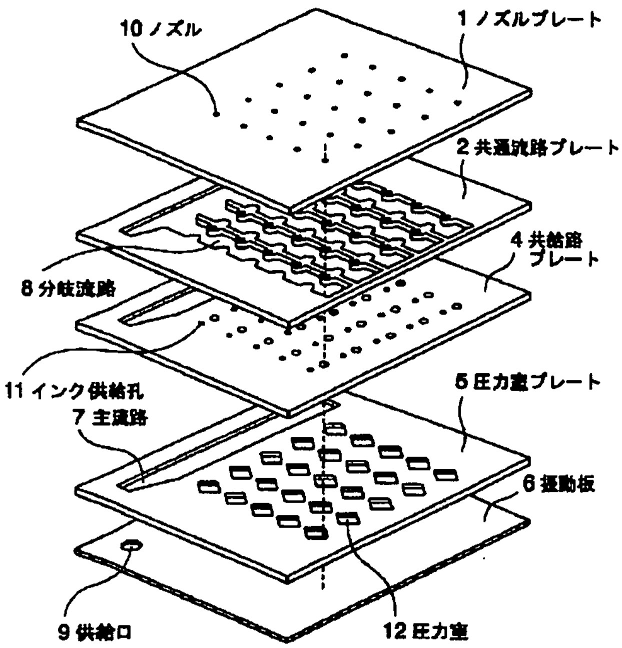

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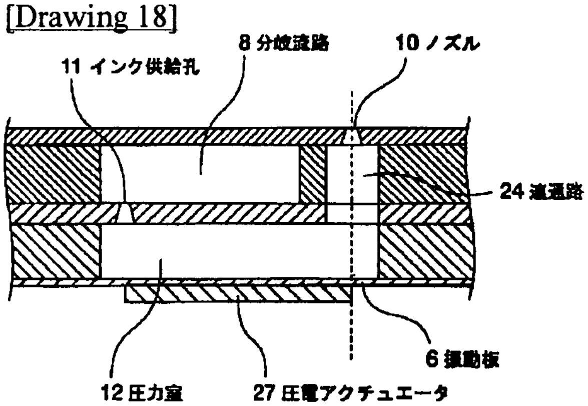
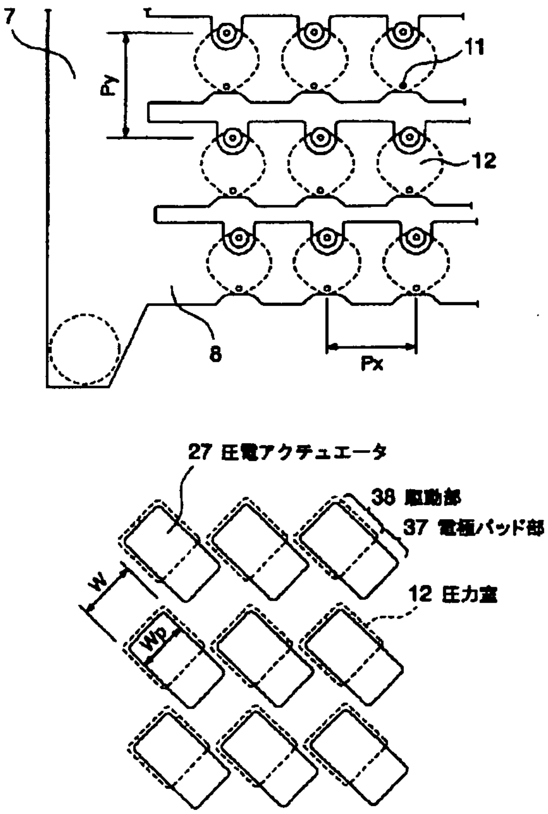


[Drawing 19]

(a)

(b)



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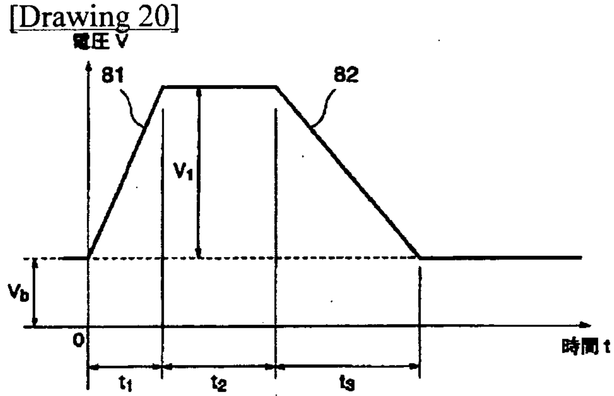

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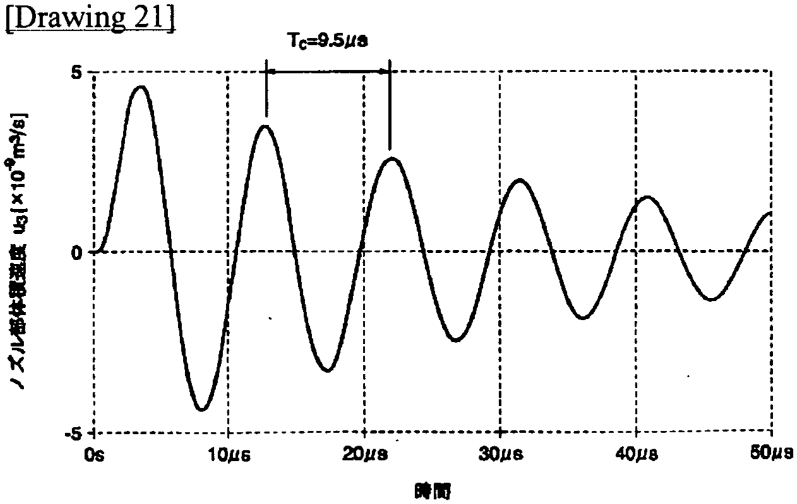

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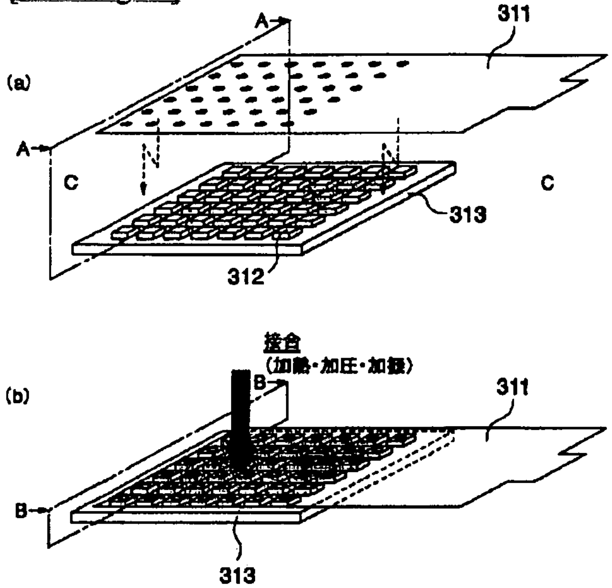

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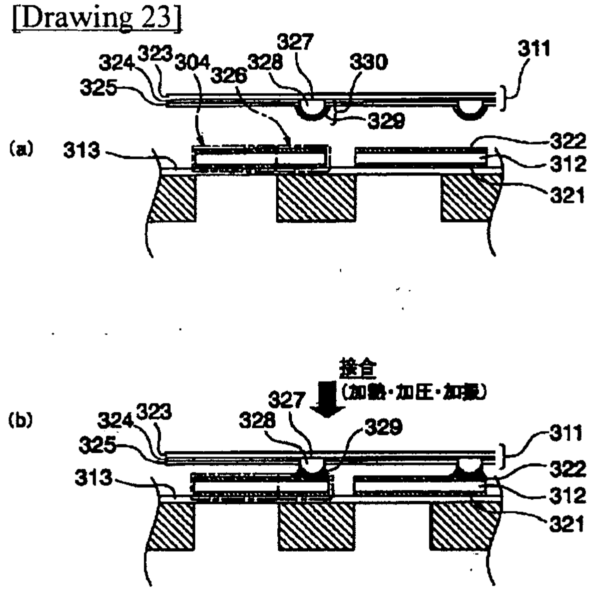

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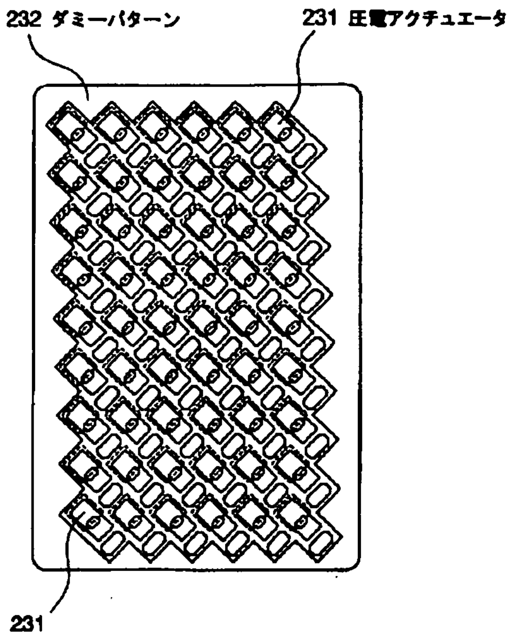

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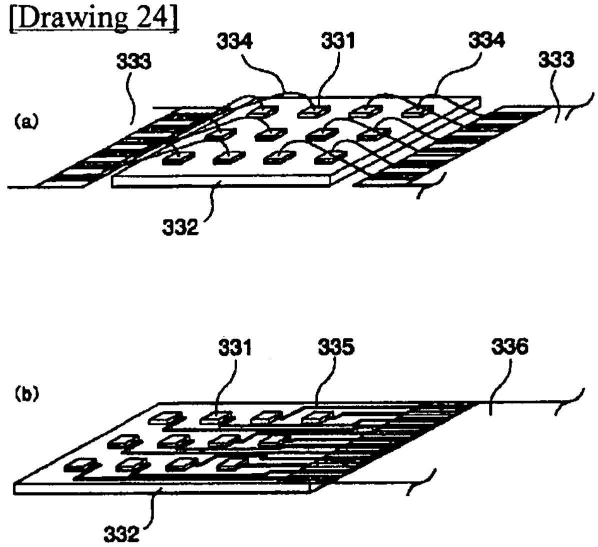

[Drawing 25]

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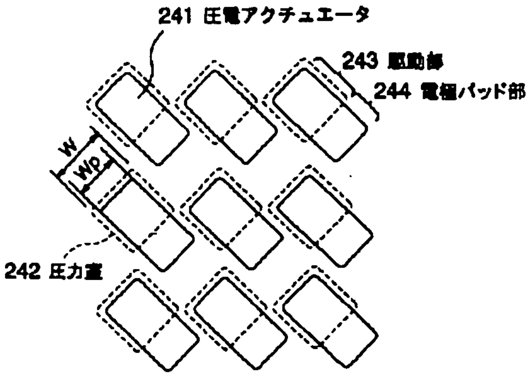

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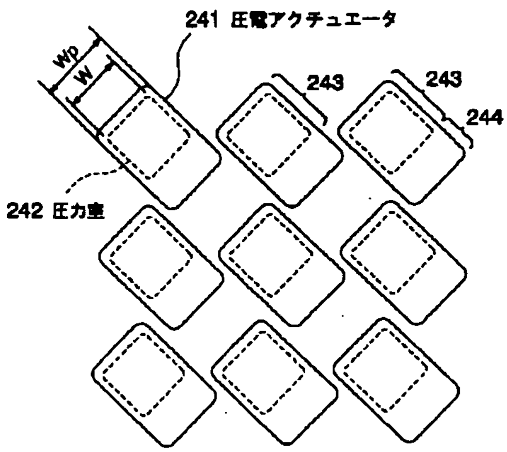

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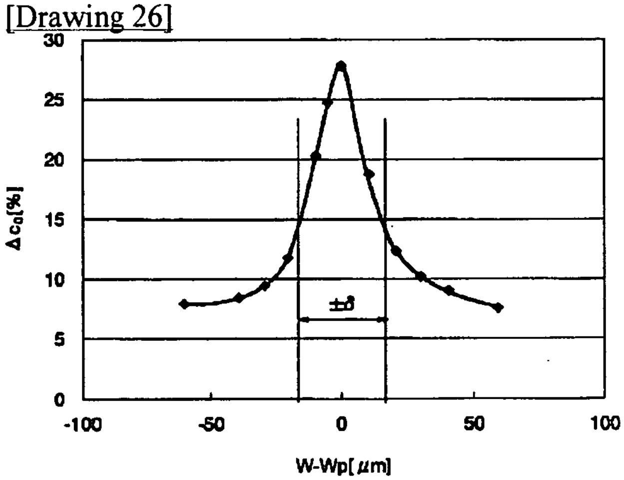

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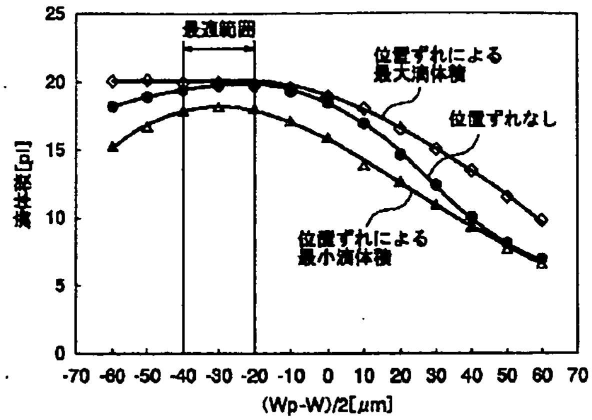

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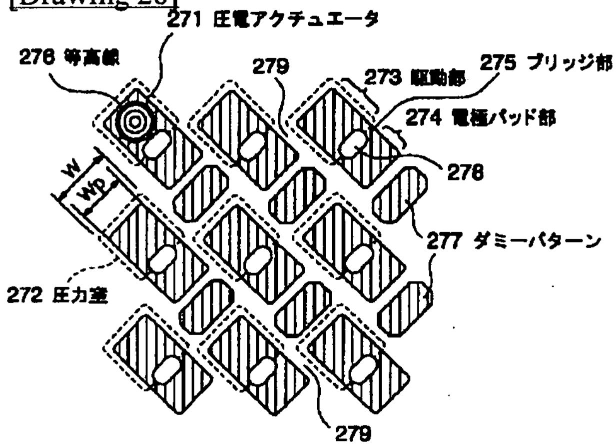

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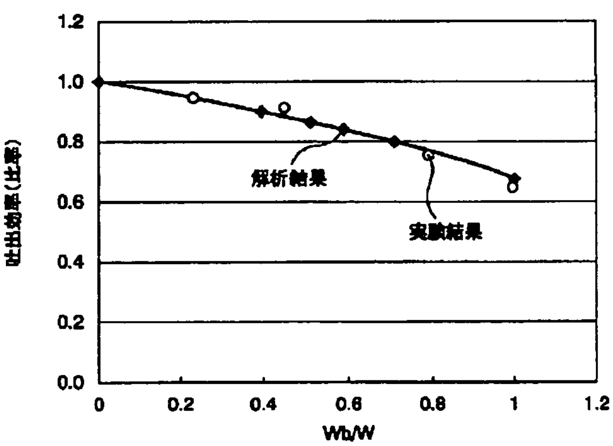

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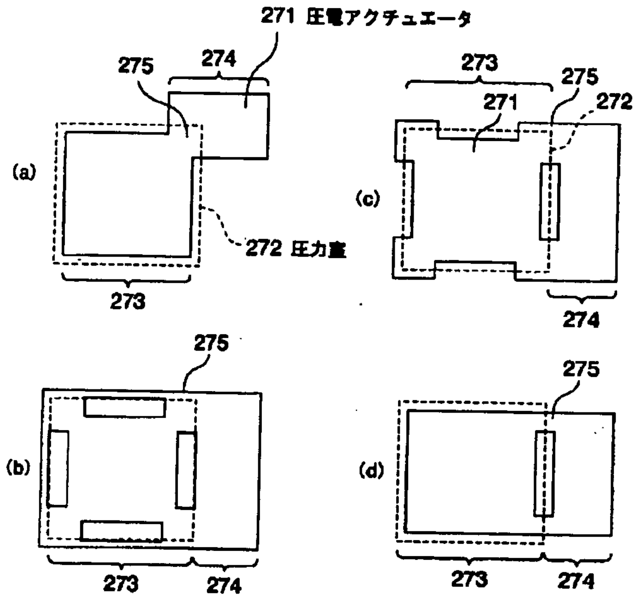

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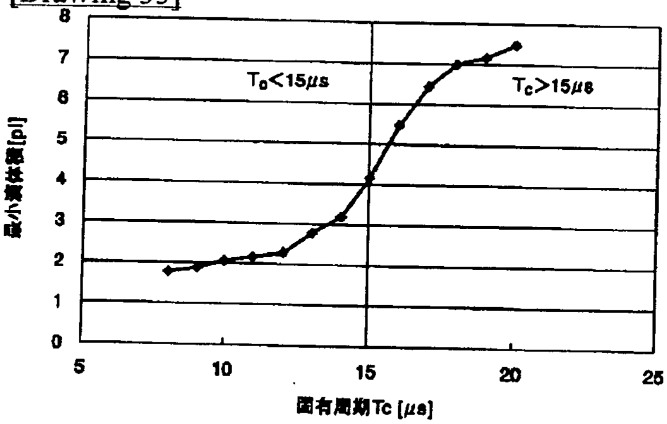

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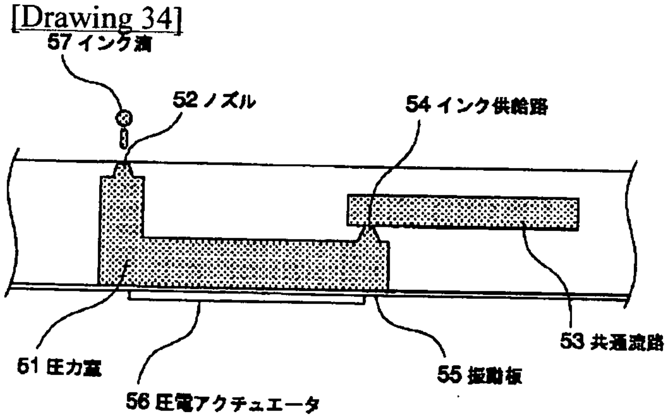

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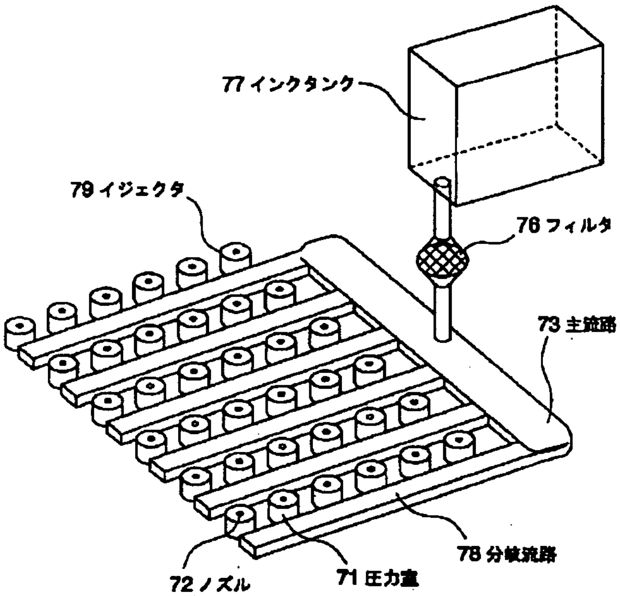

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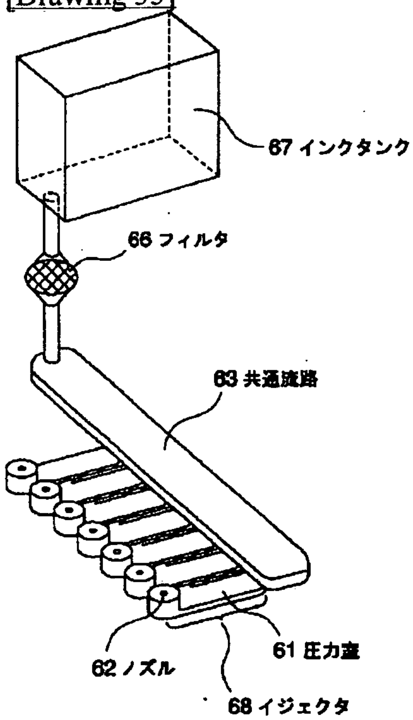

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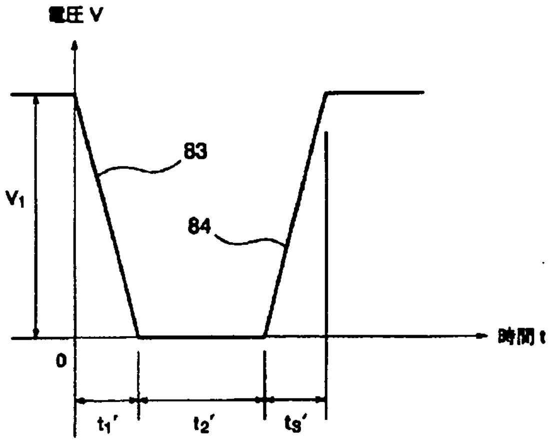

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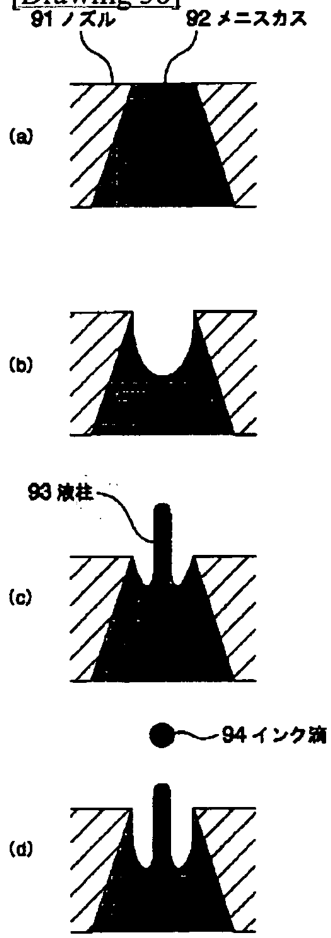

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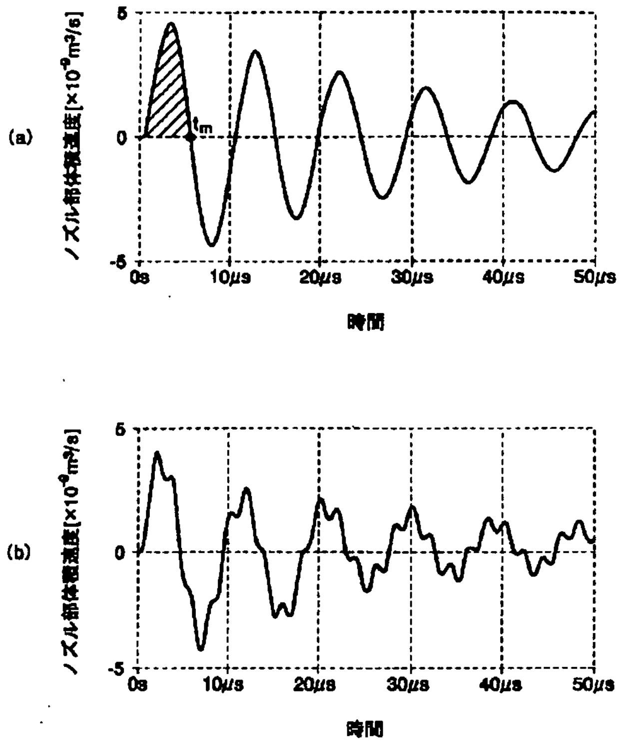

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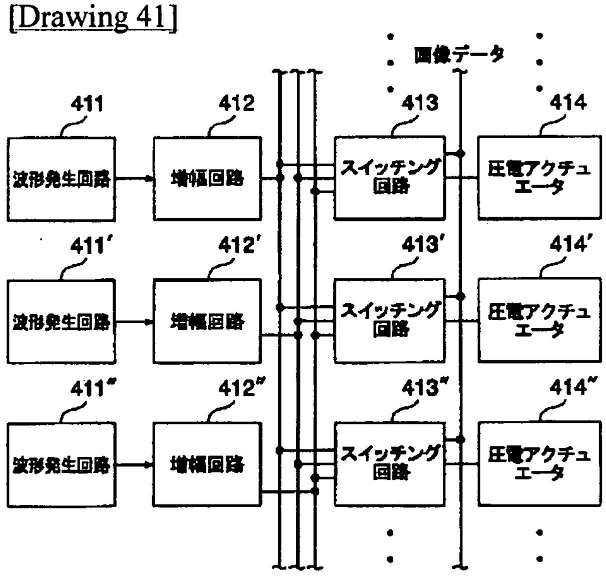

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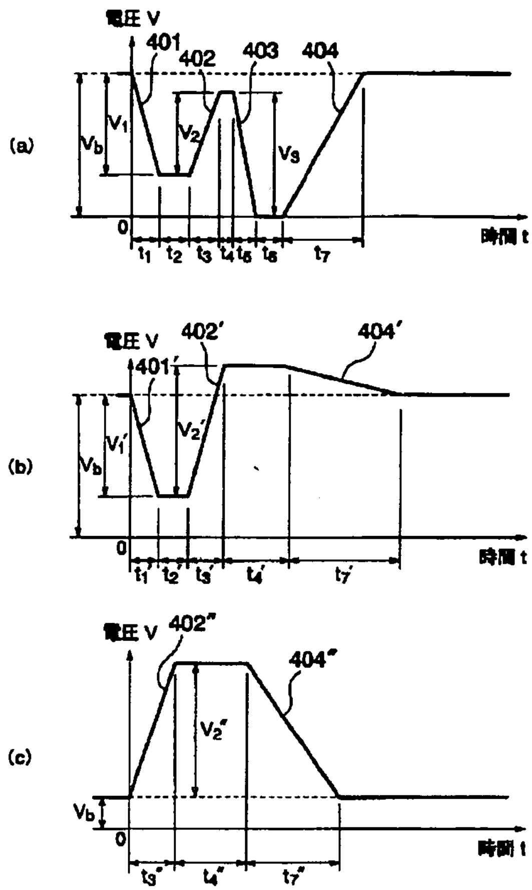

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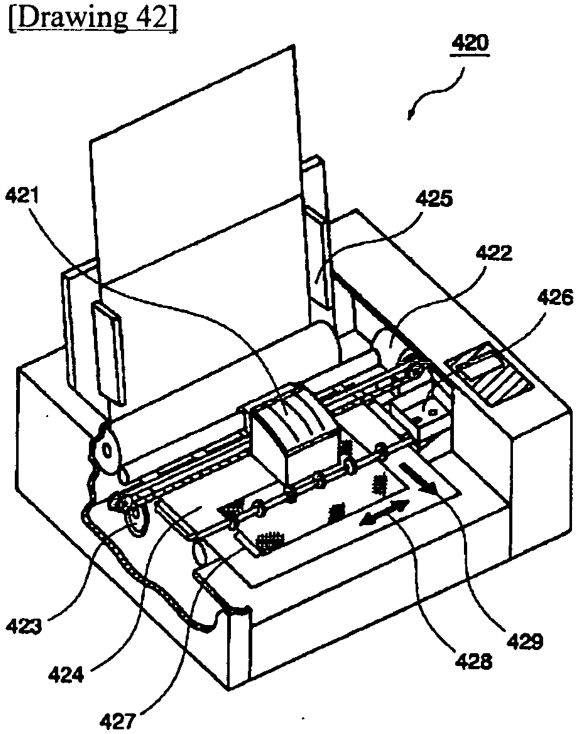

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